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ABSTRACT

Five perspectives are identified for viewing inquiry: "Guiding Principles: (for example the antecedent-consequent principle), Inquiry Factors or logical steps in inquiry, Behavioral Objectives, Affective or Attitudinal Qualities, and Inquiry into Inquiry. Many components of these perspectives are enumerated, together with related student behaviors which would exemplify the components. Two examples of class discussion which illustrate inquiry into inquiry are given and analyzed in terms of strategy. The "interim summaries" of the Invitations to Enquiry from the BSCS "Biology Teachers Handbook" are printed as an appendix, as also is the paper (Mendel's "Experiments in Plant Hybridization") on which the class discussions were based. An extensive annotated bibliography on behavioral objectives and inquiry teaching in biology is divided into five sections: Behavioral Objectives - Some Considerations, The Inquiry Process, Inquiry as a Teaching Strategy, Preparing the Teacher for Inquiry, and Evaluating the Inquiry Process. (EB)

Inquiry Objectives in the Teaching of Biology

McREL
MID-CONTINENT REGIONAL
EDUCATIONAL LABORATORY

BIOLOGICAL SCIENCES
CURRICULUM STUDY

INQUIRY OBJECTIVES IN THE TEACHING OF BIOLOGY

Developed Jointly By:

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EDUCATIONAL LABORATORY

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CURRICULUM STUDY ©

This document was written to be used by administrators, supervisors, curriculum designers, teacher educators, evaluators and students for a wide range of activities from revising current instructional objectives to developing evlauation instruments. Although the objectives were developed for use primarily at the high school level, they may be useful at the elementary and college levels. The document may be used in classroom situations in which students and teachers demonstrate varying degrees of inquiry skill and attitude development.

Recently the document has served as a basis for a doctoral dissertation (Steiner, 156). The instruments developed in this study are being used to evaluate components of the Developing Inquiry Skills program at the Mid-continent Regional Educational Laboratory.

This document is viewed as a preliminary draft rather than a final statement of objectives. Feedback on the use of this document will be helpful. A questionnaire has been inserted for your comments and suggestions.

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FOREWORD

This work is a product of a cooperative effort between the Biological Sciences Curriculum Study and the Mid-continent Regional Educational Laboratory. This effort has produced a categorization of behavioral objectives, emphasizing inquiry processes as exemplified by content. It is an impossible task to delineate all the behavioral objectives to be derived from any educational program. However, this publication presents representative examples of behaviors involving both inquiry processes and content in biological science. They are not mandatory outcomes but rather behavioral guideposts to encourage further development of a variety of specific behavioral objectives by concerned teachers. While the objectives were originally derived in relation to specific materials of the Biological Sciences Curriculum Study, they are, by their very nature, applicable to any modern course in the biological sciences. In that sense they are pervasive outcomes of teaching that combine both content and process.

Both teachers and educators of teachers will find that delineation of objectives tends to sharpen teaching goals and focus teaching methodology. As a group of examples of behavioral objectives, this publication provides entry into the self-generation of objectives for a wide variety of purposes. The objectives in this publication serve both as an introduction to construction and use of objectives and as an initial interim set of goals for modern biology teaching.

The value of cooperative efforts between Biological Sciences Curriculum Study and Mid-continent Regional Educational Laboratory is, in our judgment, established by the development of this publication, which should promote a goal shared by us all — the improvement of education.

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CONTENTS

CHAPTER ONE

RATIONALE

The Substantive Knowledge of Biological Science

The current substantive body of biological knowledge includes the knowledge of inquiry processes and the findings of these inquiries. While it is true that they are inseparable and probably are equally important, for many years in educational practice the findings of inquiry (content) have been heavily emphasized to the exclusion of inquiry processes. Recently emphasis has been placed on the inquiry processes; however, many biology teachers are not familiar with them. For these reasons, it is appropriate that inquiry processes now should be given a great deal of attention. This attention should not exclude or foreshadow the importance of teaching the findings of scientific inquiries. As a matter of fact, teaching inquiry processes demands the teaching of content inseparable from process.

The Nature of Inquiry and its Relation to the Organization and Use of this Document

Inquiry, as defined in this document, is a set of activities directed towards solving an open number of related problems in which the student has as his principal focus a productive enterprise leading to increased understanding and application.

Success in any particular inquiry involves some, but probably not all, possible inquiry behaviors and skil .. There is no attempt in this report to prescribe a definite order of inquiry skills and behaviors for any inquiry activity or for any time during a biology course. The biologist in conducting biological research, or the student in carrying out inquiry processes in the classroom, may not exhibit behaviors in the order listed. It is also understood that at the beginning of a course the student will possess certain information, cognitive skills, and attitudes that are necessary in inquiry activities. These will be applied and built upon throughout the inquiry activities.

The nature of inquiry is complex; inquiry engages the skills, interests, and attitudes of the person in an interaction with the substantive and cognitive demands of a problem as he makes efforts to rationally cope with it. Inquiry activities may vary in form and sequence from one problem to another and from one person to another person. Successful inquiry need not necessarily be terminated with the attainment of a solution to a problem, nor is the solution necessarily essential for inquiry to be deemed successful.

It is difficult to interpret a concept of inquiry so broadly conceived. Therefore, the Committee identified five "perspectives" of inquiry for analysis. Each perspective is the result of efforts to view inquriy with a particular emphasis. The five perspectives are:

1. *Guiding principles.* These represent a range of points of view or perceptions by which a biologist or student might view a given phenomenon. As an example: A scientist using the antecedent-consequent principle would seek a cause and an effect to an observed phenomenon.
2. *Inquiry factors.* These can be considered as components resulting from a logical analysis of inquiry as a problem-solving activity. Examples are: "Designing a Study" and "Formulating Hypotheses."

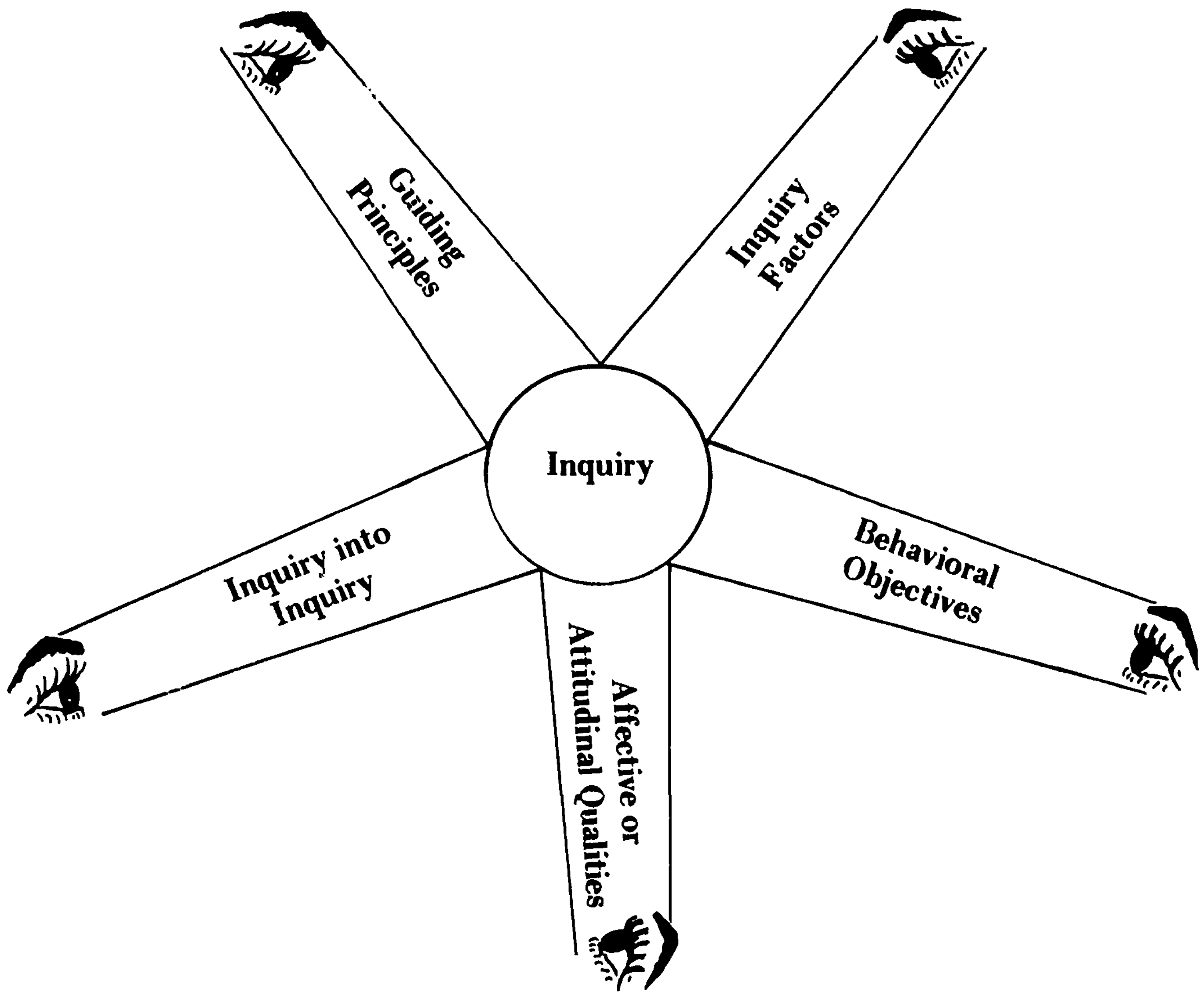
3. *Behavioral objectives.* These are specific inquiry objectives that include statements of behaviors to be demonstrated under specified conditions at acceptable levels of criterion performance.

4. *Affective or attitudinal qualities.* These are expressions of attitudes that are inferred from observable behaviors that pervade, accompany, and shape inquiry behaviors.

5. *Inquiry into inquiry.* This represents a critique of scientific research to discover the variety of logical patterns and to gain insight into the nature of scientific inquiry.

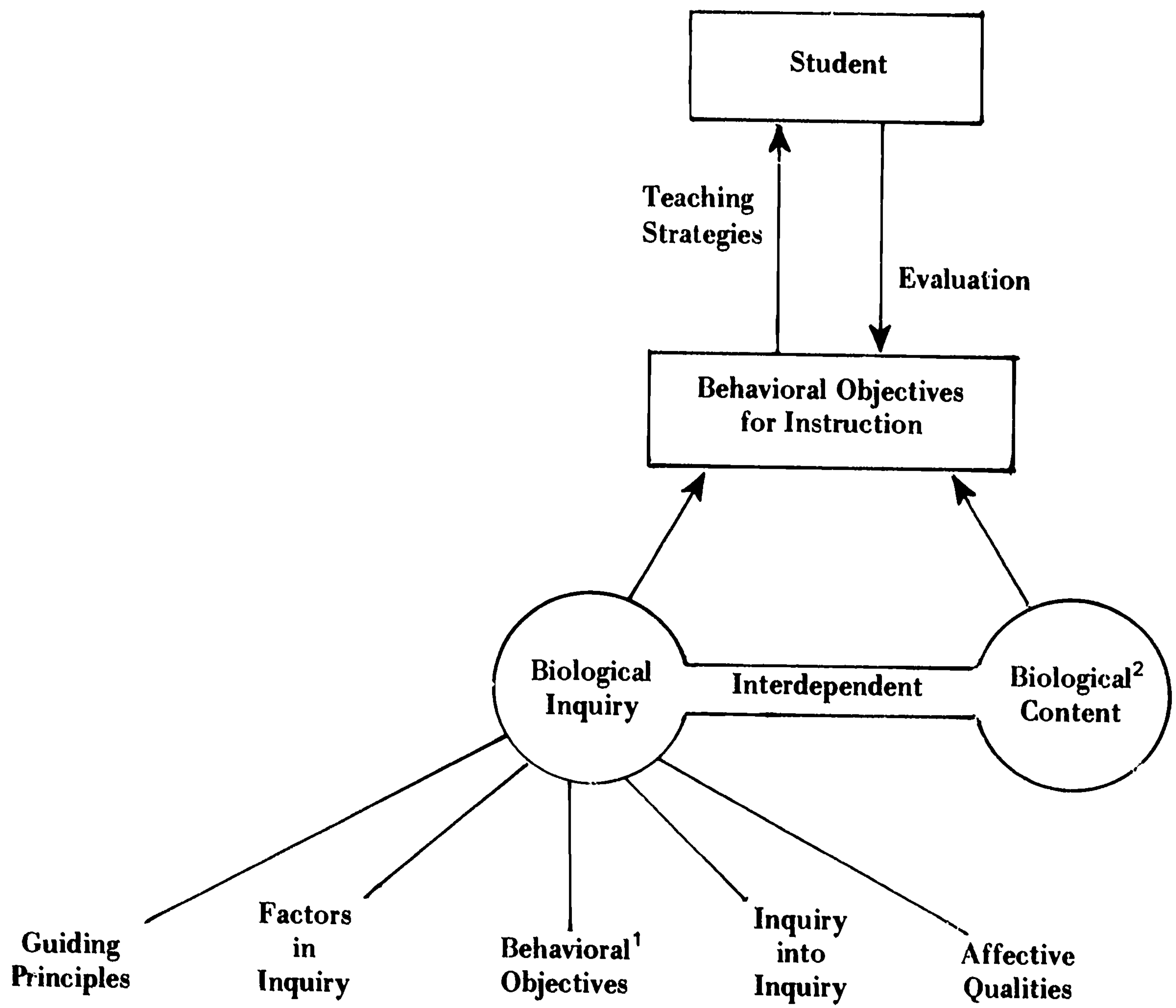
The relation of these principles to the overall nature of inquiry is shown in the figure below:

FIVE PERSPECTIVES FOR VIEWING INQUIRY



It is equally important to see how the perspectives fit into an overall instructional system with its focus on the student. The components of this model and their interrelationships are shown below.

COMPONENTS OF INQUIRY IN AN INSTRUCTIONAL SYSTEM



1. Behavioral objectives are shown as both providing a perspective on inquiry and as a means of translating an understanding of inquiry into instructional strategies.
2. Biology content is of course an essential part of the instructional system even though it has not been emphasized in the chapters to follow.

The interacting components in the two foregoing figures are, for the most part, treated in separate chapters in this report. The guiding principles presented in Chapter Two represent the five principles presently known in biological inquiry (Schwab, 137). Each principle provides a framework within which the scientist or student formulates problems and carries out six other inquiry factors presented in Chapter Three. In Chapter Four sample classes of behaviors from each of the inquiry factors and guiding principles are presented as they might appear if used to provide the framework for setting criterion performances in pre-service and in-service biology courses for teachers and their students. Following these behaviors are teaching strategies as they might be written to describe situations in which students might achieve a given criterion performance. Chapter Five includes affective and attitudinal qualities that pervade the other inquiry components presented prior to and following this chapter.

In Chapters Two through Five emphasis is largely placed on the student's use of the guiding principles and inquiry factors as he actively investigates biological problems. In Chapter Six emphasis is placed on the student's ability to critique the scientific work of others (scientific papers, etc.). Examples of classroom discussions which illustrate some desired behaviors of students are included in Chapter Seven.

The text of the document is followed by two appendices. Appendix A contains reproduced textual materials referred to or used in developing various sections. Appendix B consists of a reproduced portion of a scientific paper used for the discussions in Chapter Seven.

Finally, the document includes a bibliography of sources which can be used to develop and evaluate programs designed to attain the objectives.

It is the intent of the Committee that the document that follows aid the reader to view inquiry from each perspective without losing the overall totality of the inquiring enterprise.

CHAPTER TWO

GUIDING PRINCIPLES OF INQUIRY

Recognition and Differentiation

Although new principles may emerge in the future, five principles of inquiry have been identified (Schwab, 137) representing a range of viewpoints from which a biologist or student might view a given phenomenon (see Appendix A).[1] The student should be able to recognize and differentiate among these various principles that guide scientific studies, including his own. He should be able to determine which principle is appropriate for a study. The student should also be able to describe how the study would differ if a different principle of inquiry were used.

Principles	Examples
I. *The taxonomic principle.* This principle is based on collecting, organizing, and classifying data to develop a basis for formulating and answering researchable questions. The typical mode of inquiry is the scheme for classification implicit in the following assumptions about the nature of biological phenomena: A. There are different kinds of "things." B. "Things" can be differentiated in terms of observable characteristics.	The student measures and compares the length of lima bean seeds and later develops a problem regarding the length of second generation seed. The student, by collecting and classifying bird calls, finds some that do not fit patterns. From this discrepant event the student formulates a problem.

[1] The principles in this chapter are exemplified in the Invitations to Enquiry and the Interim Summaries presented in the BSCS *Biology Teachers' Handbook*, Chapter 4, as follows:

Antecedent-consequent principle:
- Invitations, Group I, Numbers 1-16A (includes Interim Summaries 1 and 2)
- Invitations, Group II, Numbers 17-25
- Invitations, Group III, Numbers 26-31
- Interim Summary 3

Structure-function principle:
- Invitations, Group IV, Numbers 32-37
- Interim Summary 4

Regulation and homeostasis principle:
- Invitations, Group V, Numbers 38-44
- Interim Summary 5

Self-regulatory system principle:
- Interim Summary 5

The *Taxonomic principle* is not explicitly exemplified in either the Invitations or Interim Summaries.

Principles	Examples
II. *The antecedent-consequent principle.* This principle is based on independent chains of cause and effect relationships. The typical mode of inquiry is the controlled experiment implicit in the following assumptions about the nature of biological phenomena:	In a series of experiments with proper controls, the thyroid gland is removed and the following characteristics are noted: lower temperature, lower respiratory rate, placidity, and obesity. The student should interpret that these characteristics are due to the removal of the gland.
A. The whole organism consists of many parts. B. Each part of an organism operates as an independent entity.	Gene *A* determines tallness; gene *a* determines shortness. Garden peas having *AA* or *Aa* genes will be tall, as there is no interaction between gene *A* and gene *a*.
III. *The structure-function principle.* This principle is based on interrelationships of cause and effect chains that contribute to the organism's having a certain stable character or nature. (Harvey's study of blood circulation illustrates the mode of inquiry related to this principle.)	The regulatory process is essential to life. The student might determine the role of the thyroid gland.
A. There are interrelationships of chains of causes and effects that contribute to wholeness. B. The "wholeness" of an organism has a certain stable character or nature.	Blood circulation is vital to body activities. The student determines how the heart and blood vessels are organized to accomplish body activities.
IV. *The regulation and homeostasis principle.* This principle is based on the flexibility of organs to maintain an equilibrium among changes of parts (organs, tissues, etc.) in response to changes in external conditions. Dynamic equilibrium is maintained by structural and/or functional changes *in degree* rather than kind. (The thermostat model fits this guiding principle.)	The sugar level in blood remains in equilibrium despite the fact that no sugars are digested. The sugar content in blood remains in equilibrium or balance even when excessive sugar is digested.
A. Organs are flexible and can change in response to external changes. B. A dynamic equilibrium among changes of organs can be maintained.	The student should be aware that there are several concentrations which are right for the body (depending on the condition and activity of many or all other chemicals, physical factors, and structures).

Principles	Examples
C. A dynamic equilibrium among changes will not result in structural changes or major functional changes, e.g., a transmitting membrane becoming secretory.	
V. *The self-regulatory system principle.* This principle is based on the flexibility of the organism as a whole, as well as the flexibility of the parts, to maintain equilibrium of changes to external or environmental changes. However, this principle emphasizes functional or structural changes *in kind* in the parts to make a new integrated whole.	When part of the brain is destroyed, adjacent parts may incorporate some or all functions of the incapacitated part.
A. The organism, as well as its parts, is flexible and will change in response to external changes.	
B. A dynamic equilibrium among changes can be maintained.	
C. A dynamic equilibrium among changes may result in structural changes or major functional changes.	

Skills in Carrying Out Principles of Inquiry

Depending on which of the five principles of inquiry the student uses, there will be differences in certain basic activities necessary for him to carry out the inquiry. These activities are:

(a) Asking initial questions ("What do I want to find out about the subject or phenomena of interest?");

(b) Making observations ("What data should I look for to help answer that question?");

(c) Organizing observations ("What should I do with the data to get the clearest answer to my question?").

The *principles* of inquiry become *modes* of inquiry when used as methods in carrying out inquiry. It is desirable that biology students begin to gain some understanding of these different modes. The student should be able to state a biological problem in terms of each principle of inquiry and describe the appropriate experimental design for each mode of inquiry.

I. *The taxonomic mode.* The student will carry out activities characteristic of the taxonomic mode:

A. He will ask questions.	**B. He will make observations necessary to answer questions.**	**C. He will handle data in appropriate ways.**
Examples:	**Examples:**	**Examples:**
What are the similarities and differences among the organisms found in this pond water?	See hair-like structures on the organisms found in the pond water. See internal structures of the organisms.	Make *comparisons* between observed characteristics. *Group* data according to observed similarities and differences.
What are the kinds of plants found in Prairie State Park?	See differences in leaf shapes. See differences in structure of flower parts.	Use existing classification schemes for organisms under study.

II. *The antecedent-consequent mode.* The student will carry out activities characteristic of the antecedent-consequent mode:

A. He will ask questions.	B. He will make observations necessary to answer questions.	C. He will handle data in appropriate ways.
Examples:	**Examples:**	**Examples:**
If the thyroid gland is removed from mice, what happens to their physical characteristics?	Measure temperature of mice before and after treatment. Measure respiratory rate of mice. Measure weight of mice. Provide for appropriate controls.	Organize data into tables and/or graphs which show differences in physical characteristics of the mice before and after removal of the thyroid.
What will occur if we remove *both* the islet tissue of the pancreas *and* the pituitary gland from mice?	Make observations similar to the first and last example shown above.	Organize data in ways similar to example shown above.
If I cross fruitflies with known genotypes for eye-color, can I expect results to show a simple dominant-recessive pattern?	Distinguish differences in eye-color in F_1 and F_2 generation.	Organize data to show proportion of eye-colors in F_1 and F_2 generations.

III. *The structure-function mode.* The student will carry out activities characteristic of the structure-function mode:

A. He will ask questions.	B. He will identify observations to make in order to answer questions.	C. He will identify ways to handle data.
Examples:	**Examples:**	**Examples:**
When bacteria invade a local area, such as by a scratch or puncture wound, what processes are set in motion which serve to protect the invaded organism?	Identify observations on changes in skin cells near wound. Identify observations on changes in blood vessels near wound. Identify observations on changes in blood cells.	Find ways of showing relationships, or lack of them, among observations made.
Is the migrating behavior of x species of bird initiated by changes in various organs? Are these organ changes triggered by changes in environment?	Identify observations on changes in organs. Identify observations on factors in the environment, such as day-light or temperature, which may affect those organs.	Find ways of showing relationships, or lack of them, between observations made.
What is the function of the mammal's heart in relation to the total organism?	Identify observations on changes in the structure, location, and action on the various parts of the heart. Identify observations of changes in neighboring organs following heart action.	Find ways of showing relationships, or lack of them, regarding structure, location, and action between observations made.

IV. *The regulation-homeostasis mode.* The student will recognize activities characteristic of the regulation-homeostasis mode:

A. He will recognize questions.	B. He will recognize types of observations that must be made to answer questions.	C. He will recognize ways data must be handled to answer questions.
Examples:	**Examples:**	**Examples:**
How does daily rapid walking, then running, a mile result in progressively less feeling of stress in breathing and muscular action?	Recognize observations on breathing and circulation. Recognize observations on chemical and other changes during muscular activity. Recognize observations on feelings of stress related to each factor shown above.	Find ways of relating the changes found in breathing, muscle activity, etc. to each other *and* to reduction in feelings of stress, by means of tables, graphs, mathematical analyses, and inferences.
Why does the reduction of food intake in the human eventually result in no feelings of hunger or fatigue?	Recognize observations on presence of food in stomach, blood sugar level, etc. in relation to hunger pangs and fatigue.	Find ways of relating factors to each other and to the condition of the total organism.
Years after a forest fire that destroyed most of the trees, why is there a similar forest in that place?	Recognize observations on changes in plant and animal species in that area over many years. Recognize observations on changes in environmental conditions related to changes in plant and animal species.	Find ways of relating changes in species and environmental conditions to each other and to the restoration of balances between them.

V. *The self-regulatory mode.* The student will recognize activities characteristic of the self-regulatory mode:

A. He will recognize the types of questions that stem from this view of the problem.	B. He will recognize types of data needed to answer questions.	C. He will recognize ways of handling the data to find answers to the questions.
Example:	**Examples:**	**Example:**
Will destroying a portion of the brain associated with a particular learned behavior make it impossible for the animal to relearn the behavior after recovery from surgery?	Recognize data on the repertory of behaviors that might be learned with different parts of the brain destroyed. Recognize data on changes in function and possible changes in structure of undamaged parts of brain. Recognize data on amount and regions of undamaged brain necessary for relearning.	Find ways of relating the data to show relationships between factors of the whole, changes in the whole, and evidences for new, integrated whole.

VI. *A biological situation.* The student when given a biological situation such as a pond will:

A. State a problem in terms of each of the principles of inquiry.	B. Describe the experimental design appropriate to each type of problem.
Examples:	**Examples:**
(1) What organisms (populations) are present in the pond? What is the size of each population? What is its distribution?	(1) Identify the populations present. Use sampling techniques to determine size and distribution of each population.
(2) What effect does light intensity (or other abiotic factors such as O_2, heat, etc.) have on the size and distribution of a particular population in the pond?	(2) Measure light intensity (or other abiotic factors) at various depths and locations: relate these findings to size and distribution of the specified population.
(3) What are the roles of the various populations in the food web of this pond? What changes in the web and in abiotic factors occur when there is an increase, or decrease, in the various populations?	(3) Make observations to determine food web. Introduce additional members of a specific population, or decrease their number, and determine changes in the other populations and in abiotic factors.
(4) When sewage is introduced into the pond, what changes occur in the size and distribution of the populations and in the abiotic factors? Is a new balance in the food web established?	(4) Introduce measured amounts of sewage and observe changes in abiotic factors, the populations, and their interrelationships.
(5) How much sewage may be introduced before there is a change in the original food web and abiotic factors, i.e., before a "new pond" is established?	(5) Extrapolate from results of investigation (4) to predict change(s) in original food web and abiotic factors.

CHAPTER THREE

MAJOR FACTORS IN INQUIRY

Six inquiry factors[1] have been identified that include a wide array of activities that biologists and students carry out while identifying and solving biological problems. These factors are common to all of the modes of inquiry. However, some of the related behaviors are stated in the terms of the context of the antecedent-consequent mode. The related behaviors included probably do not exhaust all of the possibilities for each inquiry factor.

Success in any particular inquiry activity may require some but not all of the behaviors presented on the following pages. Although the inquiry behaviors are presented in a logical order, no attempt has been made to bind them to a definite sequence or time. Also, in actual practice, the inquiry behaviors are closely related and may occur simultaneously rather than step by step.

Inquiry Factors	Related Behaviors
I. *Formulating a problem.* (Biologists formulate problems within identifiable contexts of the discipline.)	The student will: A. Identify one or more discrepant events: 1. In a structured situation. 2. In an open or less structured situation. B. Select (carve out) a problem for study according to the following criteria: 1. Utilization of findings from other sources (teacher, text, research reports, etc.) to select a problem. He will, for example, in the case of research reports:[2] a. Identify sources of information. b. Analyze parts and relationships. c. Describe it generally. d. Evaluate the report on criteria.

[1]The factors included in this chapter are exemplified in the Invitations to Enquiry and the Interim Summaries, presented in the BSCS *Biology Teachers' Handbook*, Chapter 4, as follows: Invitations, Group I, Numbers 1-16A; Interim Summaries 1 and 2.

[2]For particulars see Chapter Six, "Inquiry into Inquiry," page 38.

Inquiry Factors	Related Behaviors
	2. Judgment of feasibility of the problem. He will: a. Recognize there are problems that cannot be solved within man's knowledge, skill, and technology. b. Select a problem that can be solved with his present knowledge and skills. c. Select a problem that can be solved with considerations of limitations and availability of time, tools, and observations. 3. Selection of a problem which is important to him, using criteria such as: a. His interest in the problem. b. His recognition that solution of the problem provides a means for solving other problems of greater interest. c. Identification of the problem(s) as pertinent to his needs. C. State the problem in researchable terms.
II. *Formulating hypotheses.* (Hypotheses are herein defined as tentative answers to problems or questions that can be investigated. Not all investigations necessarily have stated, or even implied, hypotheses. This is most likely to be the case in studies conducted in the taxonomic mode.)	The student will: A. Identify the elements of a problem on which hypotheses could be based. B. Generate hypotheses about the critical elements in the situation. C. Clarify the statement of hypotheses: 1. Eliminate duplication.

Inquiry Factors	Related Behaviors
	2. Determine if the hypothesis is testable. 3. Determine relevance of the hypothesis to the problem.
III. *Designing a study*. (A.1-A.3 are stated in terms of the antecedent-consequent mode.)	When appropriate, the student will: A. Plan to test hypotheses. 1. Identify all of the variables possible. 2. Select a variable to be studied. 3. Establish proper controls. B. Plan for: 1. Replication. 2. Systematic observation of descriptive data. C. Plan procedures to yield wanted data. 1. Select the simplest technique to get data. 2. Select, as needed, the appropriate: a. Sample. b. Instruments and chemical procedures such as gauges, microscopes, pH indicators, etc. c. Identification keys. d. Mathematical procedures such as determination of area, volume, density, or weight. e. Mathematical operations such as addition, subtraction, multiplication, or division. 3. Identify sources of errors such as measurement, computations, tools and instruments, or operator.

Inquiry Factors	Related Behaviors
	4. Distinguish between random and systematic error. 5. Plan procedures to minimize random and systematic error such as: a. Measuring consistently. b. Practicing a laboratory technique, e.g., counting yeast cells. D. Plan a system for processing data to make it ready for interpretation. 1. Select appropriate techniques such as graphs, charts, or figures for organizing data. 2. Select appropriate statistical procedures such as determination of mean, mode, range, standard deviation, or Chi-square. 3. Record findings or significant relationships in written and oral reports.
IV. *Executing the plan of investigation.*	The student will: A. Follow the plan for collecting, organizing, and analyzing the data, and for presenting the findings. B. Use the tools properly. C. Record data accurately. (Degree of accuracy determined by the nature of the problem.) D. Review the tools and procedures used. E. Revise procedures when indicated by results.
V. *Interpreting the data or findings.*	The student will: A. Identify assumptions he has used in the study. B. Use results of other studies to interpret the data or findings.

Inquiry Factors	Related Behaviors
(Interpreting the data or findings, cont.)	C. Employ reasoning skills; 1. Deductive — arriving at a particular implication from a generalization (general to specific). 2. Inductive — arriving at a generalization from the evidence, or arriving at an interpretation by reasoning from evidence (specific to general). D. Use various means of presenting the data to bring out different features. E. Examine collected data to determine its relevance to both the problem and hypotheses at hand and to other problems. F. Identify conflicts or discrepancies in the data. G. Draw tentative conclusions. H. Avoid overgeneralizing the results: 1. Withhold judgment until sufficient data is available. 2. Restrict interpretations to limitations of the hypotheses being tested. 3. Restrict interpretations to limitations of assumptions. 4. Restrict interpretations to limitations of available evidence.
VI. *Synthesizing knowledge gained from the investigation.*	The student will: A. Relate findings to varied personal interests and to the world at large. B. Collate findings and make interpretations from several experiments.

Inquiry Factors	Related Behaviors
	C. Apply knowledge gained to new situations. (Applications are made in light of limiting assumptions and conditions.) 1. Predict additional applications. 2. Speculate about potential applications. 3. Make predictions that suggest new research problems. 4. Determine the validity of the relationship between tentative conclusions and current theories. D. Recognize new problems. 1. Identify additional research problems. 2. Design new investigations to test the validity of scientific models. 3. Design modified procedures for investigating the same problem. E. Use theories, theoretical constructs, and models as a means of relating and organizing new knowledge. F. Recognize that evidence for or against a given theory may be inconclusive. G. Recognize that a theory may or may not be testable at the time of formulation. H. Recognize that several theories may be useful, each one making a unique contribution.

CHAPTER FOUR

TOWARDS THE USE OF BEHAVIORAL OBJECTIVES TO DESIGN INSTRUCTION AND DEVELOP EVALUATION INSTRUMENTS

The basic purpose of this chapter is to demonstrate how samples of behavioral objectives for biology can be written and used with additional specificity. It is to be pointed out that the examples presented in this document are *exemplary*, not *prescriptive*.

The first section provides samples of how the objectives in "Major Factors in Inquiry" and "Guiding Principles of Inquiry" *might appear* if they are to be used by teachers or supervisors to specify classes of acceptable student performance. The objectives written at this level can provide the framework within which teachers can set terminal criterion performances for specific subject matter in their own classroom situations.

The second section provides samples of instructional strategies planned to bring about the desired behaviors in students, plus examples of the specific behavior within the context of the strategy.

Additional Specificity for Inquiry Factors (Antecedent-Consequent Mode) and Guiding Principles of Inquiry

(Symbols in parentheses refer to the objective in Chapters Two and Three from which these were derived.)

Inquiry Factors	Acceptable Student Performance
I. *Problem formulation.*	
A. Given a structured or open situation, the student will identify at least one discrepant event. (I,A; p. 14)	Communicates one problem that involves finding a cause.
B. Given problems which involve finding causes, the student will eliminate those that are not feasible. (I, B, 2, a; p. 15)	Eliminates a problem on the criterion that solution is unlikely within the present limits of man's skills. These ideas may be expressed in the student's language.
C. Given problems which involve finding causes, the student will eliminate those that are not feasible. (I, B, 2, b; p. 15)	Eliminates a problem on the criterion that solution is unlikely within the *student's* present knowledge and skills. These ideas may be expressed in the student's language.
D. Given a problem, the student will redefine it within the limits of available time, tools, and observations. (I, B, 2, c; p. 15)	Depends on existing limitations.
E. Given instructions to do so, the student will communicate to his teacher the extent to which he has utilized the following resources as aids in selecting a problem: teacher consultation, text, other students, other resource persons, books, periodicals, and research reports. (I, B, 1; p. 14)	Indicates extent to which he has utilized a particular resource. (E, 1 through E, 7 below are examples of this objective elaborated for *research reports.)*

For Research Report Utilization student will have:

Inquiry Factors	Acceptable Student Performance
1. Identified sources – author, title, journal, etc. (I, B, 1, a; p. 14)	Citation is specific enough to enable another person to find the same reference.
2. Analyzed the basic parts of the research reports, e.g., problem, hypotheses, experimental design, data collection procedures, kind(s) of data collected, ways of organizing data, interpretations and/or conclusions, and assumptions which guided the formulation of the problem and interpretation of data. (I, B, 1, b; p. 14) *(Additionally, all further parts of category E are also an elaboration of the chapter "Inquiry into Inquiry", pp. 38-43)*	The analyzed parts are recognizable as entities.
3. Analyzed the relationships between the basic and various parts of reports such as: a. Data sought and the problem. b. Interpretations and the kinds of data obtained. c. Interpretations and the way the problem was formulated. d. Assumptions, implicit and explicit, made by the researcher in relation to the problem, research design, and interpretations.	Limited by the number and scope of basic and various parts present in the report analyzed.
4. Described each report.	Summary abstract or translation written by student as a description is a comprehensive match with the original.
5. Evaluated reports in the following ways; he has: a. Judged the appropriateness of the problem and its formulation, given such criteria as feasibility limitations; time and tool limitations; research background of the author; relationship of the problem to data sought, and assumptions, both implicit and explicit.	Limited by standards to be set by the teacher for the specific report evaluated.

Inquiry Factors	Acceptable Student Performance
b. Judged the appropriateness of the hypotheses, given the criterion that the hypotheses are tentative solutions to the problem, and he:	Depends on the hypotheses under consideration. (In this and other performances which depend on statements of specifics, it is suggested that, in an objective testing situation, the student will be able to correctly answer an item consisting of five choices with one being correct.)
(1) Must identify critical elements.	
(2) Must clearly state hypotheses in the deductive sense.	
(3) Must insure that hypotheses are not duplicates.	
(4) Must insure that hypotheses are testable in that required data *can* be collected and will support or reject the hypotheses, thus contributing to solution of the problem. *(The reader is readvised that all parts of category E are elaborations of the chapter "Inquiry into Inquiry", pp.* 38-43.)	
c. Judged the appropriateness of the research design, given the following criteria:	Limited, as above, by the specific design, data collection method(s), etc. provided. (Applies to 5 c through 6.)
(1) The design must be able to yield data which can be analyzed.	
(2) The design must be structured to test for support or rejection of all the hypotheses proposed.	
(3) The design must meet the researcher's assumptions, both stated and implied.	
d. Judged the appropriateness of data collection methods given the following criteria:	

Inquiry Factors	Acceptable Student Performance
(1) Methods must fit the type of data collected.	
(2) Methods must have functioned to actually collect the data sought.	
e. Judged the appropriateness of methods of organizing data, given the following criteria:	
(1) Methods must present the data such that inferences drawn from the data relate to the hypotheses under examination.	
(2) Data could not have been organized in another way to greater facilitate inferences about the hypotheses under examination.	
f. Judged the appropriateness of interpretations and conclusions in terms of stated and implied assumptions, in and by the problem, hypotheses, research design, data collection methods, and data organization methods.	
6. Judged coherence of the whole report based on the number of interlocking relationships among all of the parts.	
7. Evaluated reports such that adequacy of the problem is judged in terms of *other* possible assumptions, pertinent evidence, and methods of gathering data.	Adequacy has been judged in terms of *some other* assumptions, pertinent evidence, and data gathering methods.
8. Evaluated reports so that the importance of the research is judged in terms of its significance to the student, the political and social times, and the potential contribution to scientific knowledge.	Importance has been judged in any way in terms of each of the three criteria.
F. Given a problem, the student will state it in researchable terms. (I, C; p. 15)	Communicates the elements of the problem on which hypotheses could be based.

Inquiry Factors	Acceptable Student Performance
II. *Formulating hypotheses.*	
A. Given a problem of a cause-effect nature, the student will identify potential independent variables, and communicate one or more (functionally separate) hypotheses which include the variable in controllable form. The student shall include evidence that the hypotheses are accepted as tenable and fruitful. The hypotheses shall take the deductive form. See "BSCS Invitation to Enquiry #10." (Schwab, 137)	
1. Given a problem statement in researchable terms, the student will list any factors which may be related to the problem on the criterion: "anything that comes to mind." (II, A; p. 15)	Any size list of any factors more than one.
2. Given a list of factors said to be possibly related to a certain problem, the student will order the factors with respect to relevance to the problem: (II, A; p. 15)	Any order of factors on the criterion that some are more "central," "important," "related," to the problem than others, or some other reason offered by the student.
3. Given a problem statement in researchable terms, the student will formulate a hypothesis. (II, A & B; p. 15)	Identifies potential independent variables.
4. Given a hypothesis, the student will clarify it. (II, C; p. 15)	The implied independent variable or variables are controllable (student gives example of at least one way of controlling).
5. Given a group of hypotheses derived from one problem, the student will eliminate duplication. (II, C, 1; p. 15)	Combines or eliminates hypotheses so that there is no duplication.
6. Given a group of hypotheses (as in 5), the student will communicate his decisions as to the testability and relevance. (II, C, 2 & 3; p. 16)	Orders the group of hypotheses on the basis of his judgment of testability and relevance.

Inquiry Factors	Acceptable Student Performance
III. *Designing a study.*	
A. Given a problem, and/or hypothesis(es), the student will communicate all the variables that might operate during a test of the hypothesis(es). (III, A, 1; p. 16)	Indicates at least one variable other than the independent variable under study.
B. Given a problem and hypothesis, the student will communicate the single independent variable that must be studied to test the hypothesis. (III, A, 2; p. 16)	Indicates as a variable that factor which is manipulated in the deductive statement of the hypothesis.
C. Given a problem, hypotheses, and list of all other operant variables, the student will communicate a plan to control the independent variables. (III, A, 3; p. 16)	Includes for each independent variable a situation in which it is held constant and a situation in which it is left free to vary.
D. Given instructions to prepare the design of an experiment (based on a hypothesis of his own or another's choice) that could be executed by others in the same way it was to be executed by the student himself, the student will prepare such a design. (III, B, 1; p. 16)	Prepares a design that, when given to others without execution plans, can yield execution plans identical to those intended or produced by the student.
E. Given instructions to do so, the student will produce evidence that he has planned for systematic observation of descriptive data. (III, B, 2; p. 16)	Displays regularity of time intervals for measurement, is constant in skills of tool use, is constant in all areas relative to descriptive observation.
F. Plans procedures to yield wanted data:	
1. Given a situation that requires gathering data, and given five means of differing simplicity for gathering data, the student will select the single simplest means. (III, C, 1; p. 16)	Selects the "means" judged simplest by the teacher.
2. Given different samples purported to represent the distribution of a given data population, the student will select the one most representative (Samples vary in n and randomness.) (III, C, 2a; p. 16)	Selects the sample judged most representative by the teacher.
3. Given instructions to communicate the correct instrument and/or technique for gathering a given set of data, the student will so communicate. (III, C, 2, b; p. 16)	Indicates instrument and/or technique judged correct by the teacher.

Inquiry Factors	Acceptable Student Performance
4. Given instructions to communicate a method of determining the area of a flat field, the student will, depending on regularity of the periphery, communicate acceptable methods. (III, C, 2, d; p. 16)	Includes formulae for finding circular, rectangular, and irregularly bordered areas (in the latter case one of several mapping procedures could be used along with a polar or hatchet planimeter).
5. Given a cylinder of 500 ml water from a lake and instructions to determine its volume, the student will determine the water column's volume. (III, C, 2, d; p. 16)	States volume to $\pm$5 ml error.
6. Given a cup of a soil of unknown density, a graduated cylinder, and a centigram balance, the student will communicate accurately the density of the substance. (III, C, 2, d; p. 16)	Includes accuracy to $\pm$ .5g/cc.
7. Given an object of unknown weight, a centigram balance, and the value of the force of gravity, the student will communicate the correct weight of the object. (III, C, 2, d; p. 16)	Includes accuracy to $\pm$ .1g.
G. Given instructions to select the most appropriate mathematical operation in a certain set of circumstances, the student will so select. (III, C, 2, e; p. 16)	Includes indication of an operation defined in advance by the teacher as most appropriate for the circumstances.
H. Given techniques and/or equipment for measuring and processing data in an experimental study, and given information that the equipment is inaccurate to a known degree above the correct figure, and that the operator habitually works within a certain set of error limits, the student will communicate that the techniques and/or equipment is *systematically* in error, and the operator error is *random.* (III, C, 3, 4; pp. 16 and 17)	Such a communication.
I. The student will also communicate the extent to which he will weight or calibrate the systematic error producer to account for its error. (III, C, 5; p. 17)	Includes calibration $\pm$ ½ of the limits of fluctuation.

Inquiry Factors	Acceptable Student Performance
J. He will or will not accept the work of the operator, given a population of data gathered by the operator representing observations of a single measure, and given similar material for four other operators. (III, C, 5; p. 17)	Includes selection of the operator whose distribution has the smallest variance, spread, or its equivalent in the student's own language.
K. Given a deduced antecedent-consequent hypothesis, its experimental design, and the nature of data to be collected, the student will communicate a plan for processing collected data so as to prepare it for interpretation. (III, D, 1, 2 & 3; p. 17)	Formulates a plan utilizing one or more of the following organizational forms: graphs (appropriate to the data), charts, or figures. Formulates a plan utilizing one or both of the following statistical procedures: measurement of central tendencies, Chi-square. Designs a format to record findings or significant relationships.
IV. *Executing the plan of investigation.*	
A. Given instructions to execute a plan which includes gathering and processing data from a controlled experiment, the student will:	
1. Produce evidence that he is gathering and processing data according to the plan. (IV, A; p. 17)	Includes a match of gathering and processing to the provided plan.
2. Use gathering techniques (or instruments), processing forms, and statistical procedures, in accordance with whatever error considerations and assumptions the techniques (or instruments), processing forms, and statistical procedures may have, to clarify the error consideration above for data collection. If applicable, an error analysis will be used to determine if actual error is within predicted limits. If not applicable, accuracy will be determined by the nature of the problem as interpreted by the teacher. (IV, B; p. 17)	Contingent upon nature of specific problem.
3. Review the techniques (or instruments) and procedures by indicating the extent to which each functioned as planned during execution of the plan. (IV, D; p. 17)	Includes such demonstrations in the student's idiom, with specific acceptance minima to be determined by the teacher for a given problem.

Inquiry Factors	Acceptable Student Performance
V. *Interpreting the data or findings.* Given processed data and a synopsis of the problem, hypotheses, and the controlled experimental design that produced it, the student will:	
A. Correctly identify the assumptions of the study. (V, A; p. 17)	Identifies at least three assumptions; one each in areas of: theoretical, operator error, instrument error.
B. Use the results of at least one of three other studies provided to interpret the data or findings. (V, B; p. 17)	Communicates the extent to which another study was used to make a judgment of support or lack of support of hypotheses by the new data or findings.
Inductive:	
C. Given a set of data, communicate a generalization. (V, C, 2; p. 18)	(From graphed data) states a relationship between two variables. This must be the actual relationship judged correct by the teacher.
Deductive:	
D. Given data and a generalization, the student will solve a problem using the generalization. (V, C, 1; p. 18)	(From a stated relationship between two variables) states the behavior of one variable when given the behavior of the other. Accuracy specific to problem involved.
E. Use at least two different means of presenting the data to bring out different features of the data. (V, D; p. 18)	Presents data two different ways judged acceptable when asked to do so by the teacher.
F. Given that there is a conflict in the data, communicate the particular conflict. (V, F; p. 18)	Includes a statement, in the student's own words, of the conflict sought by the teacher.
G. When instructed to draw conclusions from data, known by the teacher to be insufficient, withhold judgment until further data is available. (V, H, 1; p. 18)	Withholds judgment.
H. Will select from a list the one interpretation which is limited to the restrictions of the hypotheses. (V, H, 2; p. 18)	Selects the one judged correct by the teacher.

Inquiry Factors	Acceptable Student Performance
I. Will select from a list the one interpretation which is limited to the restrictions of assumptions available. (V, H, 3; p. 18)	Selects the one judged correct by the teacher.
J. Will select from a list the one interpretation which is limited to the restrictions of evidence available. (V, H, 4; p. 18)	Selects the one judged correct by the teacher.
VI. *Synthesizing knowledge gained from the investigation.*	
A. Given limited antecedent-consequent conclusions, supporting data, and other experimental reports, the student will demonstrate that he has compared these data and conclusions with data and conclusions of similar and/or replicate studies. (VI, B; p. 18)	Includes a comprehensive communication of similarities and differences as they actually exist.
B. Given limited antecedent-consequent conclusions, supporting data, and comprehensive knowledge of match of one study's data and conclusions to similar and/or replicate studies, the student will list applications of this study. (VI, C; p. 19)	Lists at least two applications where applications are possible as defined by the teacher.
C. Given limited antecedent-consequent conclusions, supporting data, comprehensive knowledge of match of one study's data and conclusions to similar and/or replicate studies, and instructions to resolve a new and related problem, the student will predict the nature of the new problem's solution. (VI, C, 1; p. 19)	Includes any application of the limited conclusions of the studies given originally and in similar or replicate studies.
D. Given a report of a research study, including tentative conclusions, and given current theories that seek to account for such phenomena as were considered problematic in the study, the student will communicate that the conclusions are (are not) validly related, i.e. accounted for, not contradictory to the current theories. (VI, C, 4; p. 19)	Depends, for a positive or negative answer, on the problem and theories given.

Inquiry Factors	Acceptable Student Performance
E. Given a report as above, its findings, and a list of "every-day" occurrences or adolescent interests, the student will select the occurrence or interest most closely related to the findings. (Ideally this objective would be measured unobtrusively rather than through an objective test item.) (VI, A; p. 18)	Is problem specific as above.
F. Given (as above), the student will identify at least one new problem in which a cause of some phenomenon is not known. (VI, D, 1; p. 19)	Includes a problem defined from the same general area as the given problems, and which would not have been recognizable had not the previous studies been undertaken.
G. Given a theoretical model, the student will communicate an experimental procedure designed to produce data which will (through interpretation) support, fail to support, or contradict the theoretical model. (VI, D, 2; p. 19)	Depends on structures and designs given by teacher and students. Data must be able to support, fail, or contradict.
H. Given a problem which he has already studied and concluded about, the student will communicate a modified procedure for reinvestigating it. (VI, D, 3; p. 19)	Communicates at least one such procedure (must be not identical to original).
I. Given a list of theories and a new problem with related observational data, the student will select the theory which best relates or organizes the data pertaining to the new problem. (VI, E; p. 19)	Selects *the one* theory that will from a list of five.
J. Given a set of inconclusive evidence for or against a theory, the student will categorize the new evidence as inconclusive. (VI, F; p. 19)	Marks "inconclusive" the one such set of evidence from a total of three sets, two of which are conclusive as judged by the teacher.
K. Given instructions to test a theory of life on other planets, the student will communicate that we are not capable at this time of testing this theory. (VI, G; p.19)	Includes such a statement in the students own words.
L. Given several different theories that account for a certain phenomenon and faced with the necessity to explain the phenomenon, the student will select the most appropriate of the several theories. Additionally, the student	Selections and statements (in his own words) as such. (Given wide variance in appropriateness of theories provided.)

Inquiry Factors	Acceptable Student Performance
will communicate that neither theory is broadly "most correct," but rather each functions as a useful tool in instances where the other(s) do not. (VI, H; p. 19)	
VII. *Differentiation of the various principles of inquiry.* (Parenthetical references are for the chapter "Guiding Principles of Inquiry: Recognition and Differentiation.")	
Principles of Inquiry	
A. Given examples of the various principles of inquiry, the student will select the example which is antecedent-consequent, label it as such, and separate this particular study from the others by listing its differences and by stating that it involves finding causes of effects. (II; p. 6)	Includes such behaviors communicated in the student's own words.
B. Given a problem which involves finding a cause, the student will state which principle of inquiry is appropriate. (Chapter Two, Introduction; p. 5)	Includes a comprehensive and operational communication of the antecedent-consequent principle, in the student's idiom, which is functionally identical to the formal definition.
C. Given a completed study in one principle, the student will list changes which would apply throughout the study if a different principle of inquiry were used. (Chapter Two, Introduction; p. 5)	Depends on principle-change and problem area. Example below: In changing from a cause-effect study to a taxonomic study, operations would cease with classification of data into categories. The classification would be the end in and of itself, with literature reviews directed at refining collection methods or supporting use of a taxonomic scheme. A change from the taxonomic to the antecedent-consequent principle is not likely without reformulation of the problem itself.

Samples of Instructional Strategies to Bring about Desired Behavior.

The page numbers below, as in the previous chapter, refer back to Chapters Two and Three. Only the last entry in this section refers to Chapter Two.)

I. *Formulating a problem.*

(I, A; p. 14)

The teacher might present BSCS "Invitation to Enquiry #10" (Schwab, 137) to class in such a way as to give raw information about sickness occurring, ceasing, and reoccurring upon moving to Boulder, to Chicago, and back to Boulder. Satisfaction of this objective would be evident when a majority of students or teams formed a causal problem such as:

"What caused the sickness in Boulder?" or:

"What was in Boulder that made them sick?" or:

"Could something present in Chicago, but not in Boulder, be responsible for their sickness?"

II. *Formulating hypotheses.*

(II, 3; p. 16)

The class if faced with a problem relating to "Invitation to Enquiry #10": "What caused the sickness in Boulder?" The teacher might lead them to suggest possible causes and to phrase their statements about cause in a deductive mode: If..., then.... Acceptable student performance would be reached when all individuals or teams generate at least one such statement in which manipulation of some potential independent variable is suggested. Example:

For *pollen allergy* as a possible cause: "If we wear pollen filtering masks while in Boulder, then we should not get sick."

III. *Designing a study.*

(III, C; p. 16)

The class has accepted the problem: "What is the role of the lateral line system in fish?" An hypothesis, that the lateral line system is a light-sensory system, has been selected as a possible explanation. The teacher has lead the class to form this hypothesis in the deductive sense: If we interfere with the ability of this system to receive light, then the behavior of the fish will be affected. The class has also been exposed through discussion to the potential influence of other factors, such as sound and temperature, as possible stimuli to the lateral line system. The teacher suggests that they design a controlled experiment which will test their hypothesis. Evidence of attainment of this objective would be production by each team or individual of a design which interferes with the ability of the lateral line system to receive light while enabling it to receive sound and be exposed to different temperatures.

IV. *Executing the plan of investigation.*

(IV, A, B and C; p. 17)

The class has just started to perform a laboratory activity which requires titration and specific calculation in order to be able to

record number of millimoles of exhaled CO_2. The teacher moves among the teams or individuals as they work. She checks whether or not the physical manipulations and mathematical calculations are being performed according to the plan provided in the laboratory guide. Evidence of successful performance is manipulation and calculation exactly as called for in the plan.

V. *Interpreting the data or findings.*

(V, C, 2, Induction; p. 18)

The students, in teams or as individuals, are shown a graph which relates frequency of chromosome breakage to *uv A* for maze. The teacher samples understanding and explains where needed until all comprehend that the relationship between the variables is expressed by the plotted points. The teacher then shows the class the absorption spectra (sampling and explaining to assure comprehension this far) of a certain nucleic acid, and two or three other materials for *uv* energy. She invites discussion, by the whole class or within teams, of the possible relationship between the first and second showings with respect to the nature of chromosomes. The ensuing discussion produces evidence of attainment of this objective if the inference is made from the curves that chromosomes might be made of nucleic acid.

(V, C, 1, Deduction; p. 18)

Given the above introduction and continuing with the same topic the teacher asks, "Which of several *uv* frequencies would be most likely to break a strand of nucleic acid?" Successful performance is attained when students select frequencies common to the chromosome breakage graph and nucleic acid absorption graph (or, more simply, any frequency represented at a peak on the chromosome breakage graph) as only this information is needed, once the V, C, 2 relationship above is accepted, to strongly infer the correct frequency for breakage of nucleic acid.

VI. *Synthesizing knowledge gained from the investigation.*

(VI A, B, C, & E; pp. 18-19)

The class has studied Mendel's and Sutton's work and has an understanding of (a) Mendel's conclusion that germ-cells in respect to each character are pure, and that these characters are transmitted independently, and (b) Sutton's observations of chromosome behavior during germ-cell division. During an open discussion of these papers, the student can show the relationship between these findings, thus indicating attainment of this objective, by describing the parallel between purity and independent transmission of hereditary factors and the structural integrity and independent assortment of chromosomes.

VII. *Differentiating the various principles of inquiry.*

(Guiding Principles of Inquiry, II; p. 5)

The class has studied Mendel's paper, "Experiments in Plant Hybridisation." The students can recognize that the first part of the study was in the taxonomic mode, that the second part ("The Reproductive Cells of the Hybrids") is in the antecedent-consequent mode, and can describe the differences in problem-formulation and experimental design of the two parts which justify the distinction between the two modes. During a discussion of Mendel's paper aimed at differentiating the guiding principles of inquiry, the objective (to differentiate) will have been obtained if each team of students differentiates as above for each part of the paper.

CHAPTER FIVE

AFFECTIVE OR ATTITUDINAL QUALITIES OF INQUIRY BEHAVIORS

Among behaviors important to success at inquiry are those sometimes termed *affective* or *attitudinal*. Although a variety of these behaviors seem to pervade the entire inquiry process, no consistent method of identifying, describing, or measuring their extent is now available. Their importance, however, is not to be negated or minimized. As more is known about them, they will be accorded more specific and detailed attention and treatment. Steiner (156) has recently operationalized and measured some of these objectives.

Many of these behaviors are difficult to identify because no verifiable psychomotor response can be associated with them. Yet, certain observable behaviors may reasonably be taken as indicative of affect or as expressions of attitude. To that extent, a sampling of those behaviors has been included here as desirable objectives of the inquiry experience.

No attempt has been made to be all inclusive, to prescribe sequence, or to associate these behaviors with particular activities. It is assumed that students will demonstrate these and other desirable behaviors to varying degrees at the beginning of the course and will apply and build on them throughout their inquiry experience. It is further assumed that the student perceives his role in the inquiry process as one of a voluntary active participant rather than a passive receptor.

Attitude or Quality		Related Observable Behavior
I. *Curiosity.*	The Student:	A. Expresses a desire to investigate new things or ideas.
		B. Expresses a desire for additional information.
		C. Asks for evidence to support conclusions made from scientific materials.
		D. Expresses interest in scientific issues in the public domain.
		E. Expresses a desire for explanations.
II. *Openness.*	The Student:	A. Demonstrates willingness to subject data and/or opinions to criticism and evaluation by others.
		B. Seeks and considers new evidence.
		C. Expresses the realization that knowledge is incomplete.
		D. Expresses knowledge of the tentative nature of conclusions as products of science.

Attitude or Quality		Related Observable Behavior
III. *Reality orientation.*	The Student:	A. Demonstrates knowledge and acceptance of his limitations.
		B. Expresses awareness that change is the rule rather than the exception.
		C. Expresses awareness of several sources of knowledge.
		D. Expresses awareness of the fallibility of human effort.
		E. Expresses belief in science as a means of influencing the environment.
		F. Does not alter his data.
		G. Demonstrates the realization that research in science requires hard work.
		H. Demonstrates awareness of the limitations of present knowledge.
		I. Expresses awareness of the historic development of patterns of inquiry and of the processes and characteristics of science.
		J. Demonstrates belief that the search for desirable novelty should be tempered by awareness and understanding of traditional concepts.
IV. *Risk-taking.*	The Student:	A. Willingly subjects himself to possible criticism and/or failure.
		B. Expresses his opinions, feelings, or criticisms regardless of the presence of authority.
		C. Participates freely in class discussions.
		D. Indicates a willingness to try new approaches.
V. *Objectivity.*	The Student:	A. Indicates a preference for statements supported by evidence over unsupported opinion.

Attitude or Quality		Related Observable Behaviors
		B. Indicates a preference for scientific generalizations that have withstood the test of critical review.
VI. *Precision.*	The Student:	A. Indicates a preference for coherent statements.
		B. Seeks definitions of important words.
		C. Demonstrates sensitivity to the appropriateness of general and/or specific statements in a given context.
		D. Expresses the need to examine a problem from more than one point of view.
VII. *Confidence.*	The Student:	A. Expresses confidence that he can achieve success at inquiry.
		B. Demonstrates willingness to take "intuitive leaps."
VIII. *Perseverance.*	The Student:	A. Pursues a problem to its solution or to a practical point of termination.
IX. *Satisfaction.*	The Student:	A. Expresses satisfaction with the process of inquiry.
		B. Expresses confidence that his inquiry experience will enable him to attain future goals.
X. *Respect for theoretical structures.*	The Student:	A. Demonstrates awareness of the importance of models, theories, and concepts as means of relating and organizing new knowledge.
		B. Demonstrates awareness of the importance of currently accepted theories and concepts as a framework or basis for the emergence of new knowledge.
		C. Demonstrates awareness of the importance of scientific procedures to the generation of new knowledge, theories, and concepts.

Attitude or Quality		Related Observable Behaviors
XI. *Responsibility.*	The Student:	A. Is active in helping to identify and establish learning goals.
		B. Demonstrates willingness to work beyond the assignment.
		C. Insists upon adequate evidence on which to base conclusions.
		D. Suggests changes to improve procedure.
		E. Shows respect for the contributions of others.
		F. Demonstrates willingness to share knowledge with others.
		G. Offers a rationale for criticism.
		H. Initiates action for the benefit of the group.
XII. *Consensus and collaboration.*	The Student:	A. Demonstrates willingness to change from one idiom, style, or frame of reference when working with others.
		B. Calls upon other talent from within the group when opinions and help are needed.
		C. Seeks clarification of another person's point of view or frame of reference.

CHAPTER SIX

INQUIRY INTO INQUIRY

There are means other than direct laboratory experiences to involve students in inquiry. One means consists of allowing students to critique scientific papers, (See Appendix B for example) abstracts, or other reports to discover the variety of logical patterns in scientific investigations carried out by scientists and science students. This type of activity can be challenging and can help students develop skills and appreciations of critical reading and thinking that are generalizable to other types of communication. Assuming that the majority of students enrolled in biology will become consumers of science rather than scientists, these skills and appreciations are very important.

I. *Analyzing research for its basic parts.* The student will identify:	**The student might ask**
A. The problem.	What question was the investigator concerned with? Was the problem stated explicitly? How did the investigator limit the problem, e.g., organisms studied, factors looked for, time over which data was collected?
B. The hypotheses.	What initial guesses did the investigator make? How did he select among these? What consequences, if any, did he predict from his best guess?
C. The experimental design.	What plan was used to answer the question? What were the experimental factors? What other variables were identified? What controls were used?
D. The procedures for collecting the data.	What procedures were used? What instruments, tools, etc. were used? What procedures were made for replication?
E. The kind(s) of data collected.	Were verbal descriptions, diagrams, etc. constructed? Were qualitative and quantitative measures taken? Were sampling techniques used?

	The student might ask
F. The ways of organizing the data.	How were the data organized? Were graphs, charts, and/or statistical procedures used?
G. The interpretations and/or conclusions.	What assumptions were made in making the interpretations? Were discrepancies or conflicts in the data identified? Were interpretations made within the limits of the original problem and hypothesis?
H. The assumptions, both explicit and implicit, that guided the researcher in formulating the problem and interpreting the data.	What ideas about the nature of the problem situation does the investigator take for granted, e.g., single factor, multiple factors, discrete entities, dynamic system, stable system, linear causal chains, cyclical causal chains?
II. *Analyzing relationships among basic parts.* Examples are:	
A. Data sought and the problem.	Are the data sought consistent with the way the problem is stated? Are the means of collecting the data consistent with the way the problem is delimited? In his experimental design he selected plants with particular characteristics. Why?
B. Interpretations and the kinds of data obtained.	Do the interpretations "fit" the data? Do they go beyond the data? Are they more limited than the data warrant?
C. Interpretations and the way the problem was formulated.	Do the interpretations provide an answer to the problems as stated? Do they show the need for additional data in order to adequately investigate the stated problem?

	The student might ask
D. Implicit and explicit assumptions made by the researcher in relation to the problem, research design, and interpretations.	What assumptions were made in delimiting or formulating the problem? What assumptions were made in designing the study? What assumptions were made in interpreting the data?
E. Among other combinations of the above:	Were the assumptions made in formulating the problem taken into account in interpreting the data?

(Examples are stated in general terms; they would be phrased more specifically when referring to particulars of the given report.)

III. *Evaluating a research report.*

A. Evaluate the components of the study (where present).

1. Problem and its formulation.	Is the problem stated as clearly as possible given the prior knowledge available that is relevant to the problem? Why or why not?
2. Hypotheses.	If an hypothesis is not stated, was it necessary to do so given the type of problem? Why or why not?
3. Research design.	Were the assumptions used in designing the study the most appropriate? Could others have been used? Why or why not?
4. Methods of collecting data.	Were all the available techniques for collecting the data considered? What is the investigator's justification for using the methods selected rather than other possible ones?
5. Methods of organizing data.	Would other methods of organizing the data have made certain features of them more apparent? If statistical procedures were used, were the assumptions in them consistent with the assumptions of

	The student might ask
	the problem and design of the study? Were the statistical procedures applied correctly?
6. Interpretations and conclusions.	Could other possible interpretations have been made? If statistical procedures were used, is the interpretation based only on the statistical relationships or is there substantive evidence for the interpretation also? If there are discrepancies or conflicts in the data, how does the investigator justify his treatment of them?
B. Evaluate the interlocking relationships of all parts which form the coherent whole. (Questions listed for II, "Analyzing relationships...," are also pertinent here, but in addition would ask for justification and for reasons for coherency or lack of it.)	Are the relationships stated or implied? Did the investigator overlook some possible relationships?
C. Evaluate the adequacy of the problem in terms of other:	
1. Possible assumptions.	Are there other assumptions that might have been made? Would these have provided additional clarification or delimitation of the problem? Why or why not?
2. Pertinent evidence.	Are there other kinds of evidence that could have been considered? If these had been used, would the data be more complete? Why or why not?
3. Methods of gathering data.	If other techniques for gathering the data had been used, would the data be more complete? Would fewer assumptions have had to be made? Would the interpretation have had better supporting evidence? Why or why not?

	The student might ask
D. Evaluate the significance of the scientific paper to:	
1. The student himself.	What do the findings of this study mean to me?
2. The political and the social times.	What light does this study throw on contemporary issues? Does it help me understand, e.g., the arguments pro or con on population control? Does it provide evidence pro or con?
3. Scientific knowledge.	Have I learned something new about modes of investigation?
IV. *Comparing scientific papers.*	
A. Compare several research reports that deal with closely related problems, yet give similar and/or different results. Given two or more of such reports, the student will:	
1. State how they differ with respect to:	
a. Problem and/or hypotheses.	What were the similarities and differences in the way the problems were stated? In the hypotheses (if stated)?
b. Research design.	What are the similarities and differences in the designs of the studies?
c. Methods of collecting data.	What are the similarities and differences in the techniques for collecting the data?
d. Methods of organizing data.	What are the similarities and differences in methods of organizing the data?
e. Interpretations and conclusions.	Are there differences in the interpretations?.
2. Identify variations and possible causes for variance.	Were different assumptions used? Were different techniques for collecting and organizing data available? Why? Were time study differences done? In technological development of equipment?

	The student might ask
	Did one investigator take something into account that the other did not?
3. Determine if and how *different solutions* (if present) to the problem can be synthesized.	Can the differences be resolved by taking into account the variations noted in 1, a-d and 2?
4. Identify some implications of the interpretations to other problems, as well as to the one at hand.	How do the results of these studies pertain to other knowledge in this area of biology? What new problems are suggested by the results of these studies?
B. Compare several scientific papers to identify author's purpose, either basic or practical, for writing paper. Author's purpose may be to report a specific research project, to encourage research, to summarize *findings* from several projects, and/or to evaluate a research report or other scientific paper.	What type of report is this? Is it a report of a particular investigation? Does it summarize several investigations? Is its purpose to raise questions? Is it aimed at the lay reader or at other investigators in this field?
V. *Applying skills gained from analyzing research reports to other kinds of reports.*	What is the author's purpose in writing this? What is the report about? What does he say? What is the function of key statements, or parts, of the report to other parts and to the whole? What are the meanings of key terms which he uses? What are the interrelationships of the parts? Is there coherence among the parts? How adequate is it in terms of criteria I have used previously in evaluating other similar papers?

CHAPTER SEVEN

CLASSROOM DISCUSSIONS: INQUIRY INTO INQUIRY

Perhaps one of the best ways to develop an understanding of inquiry is by example. Hence this chapter includes two examples of class discussions which illustrate inquiry into inquiry (see Chapter Six). The paper under discussion is the first portion of Gregor Mendel's *Experiments in Plant Hybridisation* (Harvard University Press, 1958, pp. 1-13), which is included in Appendix B.

The two examples of class discussions are not presented as ideal models. Rather, they are typical of teachers and students who are beginning inquiry into inquiry. Both discussion patterns show much that is desirable in a discussion focused on developing an understanding of inquiry, and both deal with essentially the same parts of the report. However, the styles of the teachers and their patterns of questioning are different. It is important to recognize that these differences are not only possible, but desirable, and that there is no set strategy for inquiry into inquiry. However, it should be noted that different lines of questioning tend to elicit different student responses, and so the discussions are different from the standpoint of student participation and probable learning.

Each discussion has been annotated in order to point out various things that become apparent on analysis. The analysis has been done in terms of teaching strategy. That is, the teacher's questions and statements have been categorized in a manner designed to make apparent the strategy being used. Three sets of categories have been used for classification. Both *managerial* and *guiding* questions and statements are based on Taba's work (158)[1]. The third set of categories is based on the tasks of inquiry into inquiry outlined in Chapter Six. Other schemes could have been used for annotation of the discussions, but the three used were found to be particularly worthwhile because of their simplicity and because they bring into focus many important aspects of an inquiry discussion. In addition to the classification of the teacher's questions, occasional notes have been inserted which call attention to interesting occurrences in the discussion pattern.

The first set of categories used in annotation is *managerial.* These are questions or statements which have a managerial or psychological function and which indicate approval, disapproval, agreement, etc. Four sub-categories are distinguished: supportive, inviting more thinking, refocusing, and negative.

The second type of questions or statements *guide* the discussion and are related to the logic of the content and to the cognitive operations sought. Three sub-categories are used: focusing, extending, and lifting. The cognitive operations sought must also be specified in order to make classification of guiding questions most useful. Since the *tasks of inquiry into inquiry* involve both different cognitive operations and the logic of the content, these tasks provide the third set of categories.

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[1]See also Klinckmann (137), Chapter 5, for additional discussion of teaching strategies in relation to inquiry. Part of the material in Chapter 5 has been adapted for inclusion here.

Descriptions of Categories Used in the Annotations of the Discussions.

I. *Managerial questions and statements.* These indicate approval, disapproval, agreement, etc.

M.1. *Supportive:* provide approval, encouragement.

E.g.,, "Yes;" "That's on the right track;" "Let's see if I understand you correctly . . ."

M.2. *Invite more thinking:* probing, pursue the stated response to clarify, bring out further details, resolve inaccuracies or discrepancies.

E.g., "I'm not sure I understand your point;" "Could you clarify for us how your point relates to the topic?" "Can you give us an example?" "Can you explain for us how you arrived at that interpretation?"

M.3. *Refocuses* the content or limits of discussion.

E.g., "Remember that we only have data on one type of plant;" "We should remember that Mendel's studies were done before chromosomes had been described."

M.4. *Negative:* disapproval, discouragement, controlling.

E.g., "No, that's wrong;" "You're not thinking;" "I don't agree with you;" "That doesn't answer my question;" "That's not what you were told to do."

Obviously, the last type inhibits both thinking and verbalization whereas the first three types invite more thinking and discussion.

II. *Guiding questions and statements.* These are designed to achieve three types of purposes by different questioning strategies:

G.1. *Focusing:* establish the content or topic and the cognitive operation to be performed.

E.g., "How does the data obtained by group A compare with that of group B?"

"What do you observe in that drop of pond water?"

"What are some possible explanations of why the frog did not swallow the robber fly?"

G.2. *Extending:* continue exploration of the content by encouraging thought on the same cognitive level. (Distinguished from M.2. type because it brings in *additional content* on the same cognitive level; M.2. type asks for clarification or further specificity, etc., of content already under discussion.)

E.g., "Can anyone think of another way we might obtain the needed data?"

"What are some other questions we might ask about the changes which occurred in the pond?"

"That's an important generalization. Would anyone state it in a different way?"

(Adds to the content by providing additional examples or statements that expand or enlarge a key idea; also allows for assimilation of an important idea and encourages more students to participate by thinking about and stating the idea in their own terms.)

G.3. *Lifting:* movement of thought to a more complex cognitive level.

E.g., "Now that we've identified some of the characteristics of these animals, can we group them in one or more ways?" (from differentiation to grouping)

"What part of the data leads you to that interpretation?" (from interpretation to explanation by showing relationship)

"Assuming our generalizations about the growth of a yeast population apply to other populations, what can you predict about changes in the human population?"

III. *Tasks of inquiry into inquiry* (see pp. 38-43)

I.1. *Analysis into parts:*

- I.1.a. Identification of problem.
- I.1.b. Identification of hypotheses.
- I.1.c. Design of the study.
- I.1.d. Execution of the plan (includes procedures for collecting data, kinds of data collected, ways of organizing data).
- I.1.e. Interpretations of data.
- I.1.f. Identification of assumptions.

I.2. *Analysis of relationships among basic parts:*

- I.2.a. Data and problem.
- I.2.b. Interpretations and kinds of data.
- I.2.c. Interpretations and problem.
- I.2.d. Assumptions *re* other parts.
- I.2.e. Other relationships.

I.3. *Evaluation of research report.*

I.4. *Comparison of scientific papers.*

I.5. *Applying skills to other kinds of reports.*

Examples of Classroom Discussions

I. *First discussion of "Experiments in Plant Hybridisation," by Gregor Mendel* (see Appendix B for copy of paper).

(Left column indicates type of question or statement used by teacher. Twelve students participated, but no attempt has been made to distinguish among them in the responses.)

G.1. Focusing I.1.a. Identification of problem	T. Today we'd like to make an inquiry into Gregor Mendel's plant hybridisation paper. There are certain things we'll be looking for. To set the tone, recall when the paper was written. Now, what was the investigator concerned with?

		S.	I think he was trying to explain the pattern of different traits as they appeared in different generations, to explain the reasons for the pattern.
M.2.	Invite more thinking	T.	What do you mean by patterns?

(*Note:* Rather than telling student he is correct, and thus tending to close off the response, the teacher encourages the student to continue.)

		S.	Like how a trait would show up in one generation, then skip a generation, and then show up in a third generation. This is a pattern.
M.2.	Invite more thinking	T.	Where in the paper did you find this pattern or this problem? Was it stated specifically?
		S.	I don't think he stated it as a hypothesis, he kind of stated the results.
		S.	On page 9, where it first starts with the F_2 generation, it says that there are dominant characteristics and that the recessive ones reappear . . .
M.3.	Refocusing	T.	Do you think that's stating the problem?
		S.	Well, yes. The problem is how can one characteristic completely disappear from one generation, and then it comes back . . .
		S.	On page 4 he says, "The object of the experiment. . . was to observe these variations in the case of each pair of differentiating characters, and to deduce the law according to which they appear in the successive generations."
		S.	That's in a way a statement of his object.
		S.	Well, on the first page, deduce this law . . .
		S.	Deduce this law? What kind of law?

(*Note:* Several students respond and interact with each other without the teacher guiding until it's necessary for the teacher to provide some support or guidance. Such student interaction occurs rather frequently in this discussion.)

M.1.	Support	T.	Go ahead with what you were going to say.

S. Well, on the first page he states the problem: "So far no generally applicable law governing the formation and the development of hybrids has been successfully formulated." Actually, he didn't state what he thinks is the law, he didn't say well I think the law is thus and so. I kind of take it he has a hunch because *all* through it he brings in the possibility that there are two alleles and computes the ratios.

(*Note:* Student uses the term "alleles" which Mendel does not use. Teacher might have picked up on this for the purpose of clarifying what Mendel did say and the terms he did use.)

G.2. Extending

T. Do you agree?

S. This is the first time anyone has used mathematics, and it's something new. I think that he had an idea, well, since nothing else had come up, let me try this. Maybe I can find something explaining this differing, the recessive and dominant traits he names.

M.2. Invite more thinking

T. You think he pretty accurately states the problem?

S. He doesn't come out and say it in so many words that this is my problem . . .

G.1. Focusing
I.1.b. Identification of hypotheses

T. Let's go on, keeping in mind the nature of the problem. What initial guesses do you think Mendel might have made, in the sense of what kind of hypothesis he's working under?

(*Note:* A "what" question implies that there is a stated hypothesis. Since no hypothesis is stated in the portion of the paper used, a better question would have been, "Did Mendel state a hypothesis?" This is an example of the focusing being slightly misdirected. See refocusing below.)

S. Do you mean his big assumptions?

M.1. Support

T. Right. What were some of his assumptions?

(*Note:* Temporarily teacher shifts from "hypotheses" to "assumptions" in keeping with student's use of the word.)

		S.	I thought maybe he figured out the two alleles – the dominant and recessive. I don't know whether this was pointed out before him . . .
		S.	He was probably the first one to sit down and think about it and define recessive and dominant. I think that maybe . . .
M.3.	Refocusing	T.	Is there a place in the paper where he states his hypotheses?
			(long pause)
		S.	Well, at the very end he sort of states his conclusions, he says, ". . . the hybrids form seeds having one or the other of the two differentiating characters, and of these, one-half develop again the hybrid form, while the other half yield plants which remain constant and receive the dominant or recessive characters respectively in equal numbers." *(Note: p. 13)*
		S.	He might have thought there could have been a pattern.
M.1.	Support	T.	That's very good. You're saying then that this was his hunch, but it wasn't really stated that way. . .
		S.	He has not been sure of all the parts, he went through the experiments. . .
M.3.	Refocusing	T.	So can we say that the hypothesis was stated explicitly?
		S.	I don't believe that in this much of the paper, the section we have, he actually stated it. He just kind of drew conclusions from his data; also, I think his data was kind of slanted toward a hypothesis. I don't think he could have had the data and then just picked up any hypothesis. I think it was designed to answer what he finally reached, but I don't think he stated it in black and white.

2

G.1.	Focusing	T.	Do you think that's good for scientists to do?
I.3.	Evaluation of report		
		S.	I don't think he wanted to stick out his neck too far.
M.2.	Invite more thinking	T.	Do you think this is a quality in different investigations, not explicitly stating a hypothesis?
		S.	I don't think that the layman reading it would understand it.
G.1.	Focusing	T.	Do you suppose he wrote this paper for the layman?
I.4.	Comparison of reports	S.	I don't think people were that worried about plants.
M.2.	Invite more thinking	T.	Was there a hint of that in the paper?
		S.	It seems to me he could have written all this down as the experiment went along, but instead of leaving the paper that way, why didn't he, when he recopied it, say now, this is my hypothesis: one-half of them is going to turn out dominant and whatever, so it would make him sound good. Why didn't he do that?
M.2.	Invite more thinking	T.	Do you think it's necessary all the time to do this?
M.1.	Support		You've learned that it is.

(*Note:* Previously in the discussion, and becoming more apparent at this point, the students are confused about the hypothesis. The apparent reason for this, which the teacher recognizes here, is a well-established frame of reference which leads the students to *expect* explicitly stated hypotheses. This is probably due to dealing previously in the course almost exclusively with inquiry in the antecedent-consequent mode. The portion of Mendel's paper with which they are dealing is, however, in the taxonomic mode. Investigations in this mode characteristically do not have hypotheses, especially not of the if . . . , then . . . type.)

S. One thing that I'm thinking about is when I read something like this, and I don't know what they're looking for, I'm more likely to come up with different ideas about it too. If you know what you're looking for, then you expect it to turn out.

S. Also, if he states the hypothesis at the very beginning, and then he gives his evidence, you see this

		goes with the hypothesis, and it's a lot easier. But this way, you have to read the whole paper, and you see the conclusion at the end, and then you go back through and see how the data applies to the hypothesis.
	S.	Actually, he didn't really start his experiment right away. He does a lot of background work at first, like explaining the different characteristics of the flowers, explained why he picked this flower.
M.1. Support G.1. Focusing I.1.c. Design of study	T.	Why would he do that? We start here with experimental design. That's something we should mention. You might go ahead with it.
	S.	Why he picked these flowers?
M.3. Refocusing	T.	Yes, what were the reasons for the selection of these particular plants?
	S.	There were a lot of types; they could be protected from foreign pollen, and they had a short life cycle.
M.2. Invite more thinking	T.	Do you think that's necessary?
	S.	You have to find something to suit your purpose. It's a lot easier to look at the color of the pods or whatever, but if some plants' only differing characteristics were the size of the xylem, that would be hard to chop up all the plants and look at the xylem. You do have to choose according to the need.
G.1. Focusing I.2.e. Relation between design and problem	T.	You're saying he had to choose things according to the need. Now in his experimental design he selected plants with these particular characteristics. Why?
	S.	Because some are dominant and some recessive.

(*Note:* Student is using information learned elsewhere rather than noting function of these terms in this paper. This also occurred earlier in the discussion with these two terms.)

M.2. Invite more thinking	T.	Did he know that though?

		S.	He said that they never mixed. like some characteristics, like red or white, but no pink. There's no transitional.
M.2.	Invite more thinking	T.	How could he do that? How could he tell all that?
		S.	Well, he probably had done other experiments and got information from them, plus he lived in an agricultural area.
		S.	He'd probably seen peas before.
		S.	He selected his plants from garden peas and then grew them and selected them according to what he picked.
M.3.	Refocusing	T.	On page 2 he says experimental plants must necessarily possess constant differentiating characteristics. What did he mean by that? By "constant?"
		S.	That it appears in every generation.
		S.	Well, that wouldn't be true of what he later called recessive, they wouldn't be constant.
		S.	They never had those transitional ones.
M.2.	Invite more thinking	T.	Why was this important? It says here, "constant characters." Why would he want that?
		S.	I think he's trying to make it easier. I wouldn't want to work with pea plants for eight years.
		S	That's what his whole experiment is for, to see how these characteristics pass on. It seems logical, you know . . .
M.2.	Invite more thinking	T.	What do you mean "logical?"
		S.	How the characteristics are passed on. He's studying the way that it happens.
M.1.	Support	T.	That's all right. You're saying the *way* that it happens: observations on the plants, what they looked like. Is this what you mean by "way?" I think it is.

	S.	Well, I'm talking about the pattern, how often it happens, why the different characteristics appeared.
M.1. Support M.3. Refocusing	T.	Again you're going back to the original problem. Why would he want constant characteristics to start with?
	S.	Well, if they weren't constant, he'd have a hard time counting them. He'd have all these different. . .
M.3. Refocusing (by student)	S.	Have we decided what he meant by "constant?"
	S.	Yes, I don't understand that word at all.
	T.	In each generation it would appear the same, like pure-breeding.
	S.	By characteristic, does he mean like yellow seeds or the green seeds? Or does he just mean the color of the seeds? When he says constant characters, does he mean just the size or . . .
	T.	Either one, as long as they're constant.
	S.	Okay.
	T.	In other words, a plant that had round peas would give round peas, another kind would give wrinkled.
	S.	Yes.

(*Note:* In the classification scheme we are using for annotation, there is no truly appropriate category for when the teacher answers a direct question. The only one that might be used is "support," in that the teacher does not discourage or disparage the student for asking a "simple" question.)

G.1. Focusing I.1.c. Design of study	T.	Okay, now that we've got that settled, how about the second characteristic – protected from foreign pollen. What's he saying here?
	S.	See that maze over there? Suppose a mouse were running in it and all of a sudden he stopped, and if there were a lot of light in the room and a lot of sound in the room, you wouldn't know whether it was the light or the sound or what. You've just got

			to have one variable to affect the experiment or you don't know which one it is that's causing the disturbance, or whatever.
M.1. M.2.	Support Invite more thinking	T.	Okay, then you're saying, what are the controls; he had a plant that would not be disturbed by other pollen. Why would he do that?

(*Note:* Use of the terms "control" and "controlling" here and following suggests again that students have a strong frame of reference *re* inquiry in the antecedent-consequent mode. The teacher, in using the term, apparently recognizes its meaning for students.)

		S.	Well, when you're experimenting with different crosses, if you get pollen from an unknown, it will throw it off because you won't know which characteristics you got from the parents.
M.1. M.3.	Support Refocus	T.	All right, very good. Now the last one, "hybrid's offspring should suffer no marked disruption in fertility." What does that mean?
			(long pause)
		S.	I don't really understand it. But in the next paragraph . . .
M.3.	Refocus	T.	He's really saying that he wants plants that are what?
		S.	That are fertile.
G.1. I.1.d.	Focusing Execution of plan	T.	Let's look at the procedures that Mendel might have used in collecting the data. Do you think that he was controlling his operation rather effectively?

(*Note:* The term "might" and "controlling" tend to distort the intended focus. The most significant procedure of the crosses and the results is not, therefore, sharply emphasized in the subsequent responses. A better question might be, "What did he do in his first experiments?")

		S.	It seems to me that he was, because he has the greenhouse plants; he says something about insects. He says a certain insect could mess up the experiment, so he watched for that. I thought it sounded

like he controlled everything. The smaller plants were transplanted so they wouldn't be taken over by the bigger ones. I guess he believed in evolution, well, natural selection, because he took the smaller plants out because he realized they'd be selected against . . .

S. He was really assuming Darwin's hypothesis.

S. I just thought of something. When he did this, it really becomes sort of an ideal situation, his whole idea; it's surprising that it would work that way because, really, there are so many conditions that would affect plants. And after eight years, that there wasn't a drought or something, or even the ground. It took so much area. It doesn't say that he had trouble with different compositions of soil. Maybe there wasn't that much difference.

M.2. Invite more thinking

T. It doesn't mention that in the paper though, does it? We really don't know. We'll have to make that assumption.

S. Surely the dirt in the same garden was all the same.

T. That's an assumption now, and could we generalize and say, knowing that he had such good controls, and he was cautious, that he would probably take care of the soil?

S. Yes, if he had noticed any strange differences, he would have made note of it.

M.3. Refocusing
I.1.d. Execution of plan

T. What were some of the procedures he used in collecting the data? Now, we've stated the problem, and a little about the experimental design. We really haven't said much about the design, have we, but the controls. What about the design itself?

(*Note:* Two slightly different questions were asked here. The first one is more sharply focused than the second.)

	S.	Well, on page 3 it says, in the next to the last paragraph, he says that he's subjected the peas, the different varieties, to two year trials. And that he did that before crossing them, and that the pure breeds remained constant.
M.1. Support	T.	That's good.
	S.	He made sure of that before he started.
	S.	He spent two years just making sure he was starting out right.
G.2. Extending	T.	Any other things about the design?
	S.	Page 3, in about the middle of the page, he talks about artificial fertilization and how he did it. And another thing that he did was to make a table of all the differences. . .
	S.	Something I don't understand is, did he take a plant that had like round seeds and green or yellow albumen and all different kinds of characteristics and mixed them with others that had characteristics opposite to the first?
M.2. Invite more thinking	T.	What do you think he did?
	S.	I don't know. Seems like there's so many characteristics he worked with, but I don't know exactly what he did.
	S.	I think he divided them in sections of plants with different kinds of seeds and crossed them six times. He crossed one with the other five and notes what he is looking for.
	S.	Do you mean he took two plants which were exactly alike except for shape of seeds?
	S.	Is she saying one characteristic?
M.3. Refocus	T.	Right. Doesn't it say something about that in the paper?

		S.	Oh, so one characteristic, like wrinkled or round. And he did an experiment for each type, for each characteristic.
G.1.	Foscusing	T.	Was that a good way for him to do it?
I.2.a.	Relation of data and problem		

(Note: Question implies that reference must be made to the nature of the problem, but it problably would be clearer to the students if this were worded to show that "good" means looking at the relationship between the data and the problem. Also, it is usually better to continue with identification of parts of the report before asking questions about relationships between the parts.)

		S.	Yes.
		S.	One thing we haven't talked about that I thought was interesting was when he said he crossed them and the hybrids had, well, on page 8, he crossed a short one, about one foot, with one six feet and got some 6 - 7½ feet. What would cause that?
		S.	Seems like that is transitional. Like you mix red and white and get pink.
		S.	It's not between, it's just adding it together.
M.2.	Invite more thinking	T.	Well, what would appear to be dominant?
		S.	Long.
M.1.	Support	T.	Tall. All right, so I don't think it would be transitional.
		S.	Maybe the recessive trait with the dominant trait produced something extra.
		S.	Seems like that would be transitional.
		S.	But he says a greater luxuriance appears in all parts of the plants. It's not only taller, but has more on the plant.
M.1.	Support	T.	A healthier plant?
		S.	Yes
M.3.	Refocus	T.	Well, let's go back to selection of the plants.

S. He didn't really say what kind of results he expected.

T. Was he looking for that, though?

S. He's trying to see if there's a pattern.

M.3. Refocus

T. But remember, you said that on page 1 he has something specific he's looking for.

S. If he has a pattern, in working a mathematical formula to find the solution, I think the conclusion has to fit every case.

M.2. Invite more thinking

T. Do you think it does?

S. A mutation is an exception to the rule. How can you fit it in except as an odd one?

M.1. Support

T. Consider it another problem.

S. He does say that this will happen, on pages 6 and 7, that there are problems. I think he also says that he doesn't count them.

G.1. Focusing

T. Should he count them?

1.3. Evaluating of report

S. Separately. On their own, not with the rest of the plants.

T. Do you think it was good to put that in his paper?

S. He has to. Yes.

(Next day)

G.1. Focusing
I.1.c. Design of study
I.1.d. Execution of plan

T. We ended up discussing the problem, the procedures and some of the data. The procedures for collecting the data, we ought look at that a little more. On pages 4 and 5 he talks about arrangements of the experiments. How does he set the procedures up? What does he do with these plants, the ones that he has selected as pure-breeding plants?

S. He crossed the ones that had the differentiating characteristics, like the ones with the round and wrinkled seeds, and got hybrids.

M.1.	Support	T.	Maybe one of you would write these down as we go along. In other words you're saying what trait. Let's pick out a particular trait and see if we can follow his particular design. What trait do you want to pick?
		S.	First one.
M.3.	Refocus	T.	What did he do with this now? Write this down. What was his first cross?
		S.	Round was crossed with wrinkled.
		T.	How would you put it in letters?
		S.	R R x rr $\rightarrow$ Rr.

(*Note:* Student again is using previously learned information rather than restricting his statement to what is stated in the paper about this first set of crosses.)

		S.	It's smooth or wrinkled.
		S.	The dominant is round.
G.3.	Lifting from I.1.d to I.2.a.	T.	Why did he make that kind of cross?
		S.	He had to cross homozygous plants.
M.2.	Invite more thinking	T.	How do you know that these are homozygous plants?
		S.	He couldn't be sure, but after two years . . .
		T.	That gets back to the selection of the plant.
		S.	On page 8 it says whichever characteristic shows up in the hybrids is the dominant trait. Like when he crossed round and wrinkled peas, he got round. And so all his results show the recessive is carried in the hybrid.
		S.	But you have to go on to another generation and come back.

(*Note:* This student has stated a critically important point; it is pursued later.)

M.2. Invite more thinking	T. (Directed to other student) What do you think, he got all the offspring and they were all what?
	S. Round.
M.2. Invite more thinking	T. Now what kind of thought might have been going through his mind when he got the data?
	S. It seems like it would be half and half.
M.2. Invite more thinking	T. Transition?
	S. No. I mean half round seeds and half wrinkled seeds. That's what I meant.
G.3. Lifting (to prediction)	T. What if he got that? Let's just suppose it.
	S. He'd probably have made up a formula for that.
G.1. Focusing I.1.d. Execution of plan	T. Did he check all these traits out? Did they all show the same pattern of dominant and recessive?
	S. Yes.
G.1. Focusing I.1.e. Interpretations of data	T. But the thing that bothers me is this: How does he know this?
	S. He crossed ones that he knew what the parents were like, the parents that had the recessive traits.
	S. But how come he wouldn't say like the dominant parent is the one that is responsible?
	S. But how about when he crosses pure-breeding, wrinkled seeds?
M.2. Invite more thinking	T. Isn't that pure-breeding pretty important, from the very start?
	S. And the offspring, that's fine, some of them are going to be dominant, some recessive . . .
	S. But he has to be sure that he's just crossing the hybrids, and not mix them up with the pure-breeding.
M.2. Invite more thinking	T. Do you think that's what he did?

S. I think he had to go one step beyond, and then backtrack, so he'd know which were hybrid and which pure-breeding. But to be sure he'd have to go on to the next generation.

G.3. Lifting to
I.2.b. (Relation between interpretations and kinds of data)

T. Why would he have to go on to the next generation?

S. How would he know that the recessive was there unless he'd gone on?

(End of time: discussion not completed.)

II. *Second discussion of "Experiments in Plant Hybridisation" by Gregor Mendel.*

(Left column indicates type of question or statement used by teacher. Fifteen students participated, but no attempt has been made to distinguish among them in the responses.)

G.1. Focusing

T. Before we begin looking at the specific parts of the paper, I would like to start out in general and ask several questions.

I.1.a. Identification of problem

Why do you suppose a man would work on this topic? Do you have any idea?

S. He wanted to try out something different; he was curious.

M.1. Support

T. All right, he was curious, wasn't he, about how hybrids, well the pattern by which they transmit characteristics from one generation to another. He gives you somewhat of a hint to this in the introductory remarks as to why he chose this particular problem to work on. Can any of you pick it up there? Yes?

(*Note:* By using an M.2. type of question, e.g., "What was he curious about?", students would have had to do more thinking.)

S. That "so far no generally applicable law governing the formation and development of hybrids has been successfully formulated."

M.2.	Invite more thinking	T.	What do you think about the statement that he wrote? What is he referring to?
		S.	His motivation for doing it.
M.1. G.2.	Support Extending	T.	His motivation for doing it; yes, he was motivated because there hadn't been any law. Other comments about this? Yes?
		S.	Seems to me that no applicable law has been found.
M.1. G.1. I.1.a.	Support Focusing Identification of problem	T.	I think you're right. Let's go on to see if we can find the problem in the paper. What was the question the investigator was concerned with?
			(On page 4, under "Division and Arrangement of Experiment")
M.1.	Support	T.	Would you read it for us please?
		S.	"The object of the experiment was to observe these variations in the case of each pair of differentiating characteristics and to deduce the law according to which they appear in successive generations."
G.2.	Extending	T.	Do all of you agree with that? Is there anybody who might disagree that that is a statement of the problem?
		S.	On page 1 he states, "The striking regularity with which the same hybrid forms always reappeared whenever fertilization took place between the same species induced further experiments to be undertaken, the object of which was to follow up the developments of the hybrids in their progeny."
M.3.	Refocusing	T.	Would you read the last part of that again please, starting with "the object."
		S.	"the object of which was to follow up the developments of the hybrids in their progeny."

M.2.	Invite more thinking	T.	Do you feel that this is also a statement of problem? So I guess what we're saying is that the problem might be stated in two or three different places in the early part of the paper. Right? Do you wish to add anything to what has been said?

(*Note:* At this point the teacher might have chosen to firmly establish that these are two statements of the problem by asking the students to compare the statements. Are they really saying the same thing, the same problem? If so, what is the significance of the difference in the wording?)

G.1.	Focusing	T.	How do you suppose he felt about working on this problem?

(*Note:* A focusing question, but it is not included in the categories being used. Since it pertains more to a psychological approach to inquiry than to the logical analysis, which is the basis of our categories.)

		S.	Well, it says on page 2, it says it requires indeed some courage to undertake a labor of such far reaching extent. Then it says on down further, "Whether the plan upon which the separate experiments were conducted and carried out was the best suited to attain the desired end is left to the friendly decision of the reader."
M.1.	Support	T.	And I guess that's what we're going to be doing for the rest of the period is taking a careful look at what he did and then to consider it carefully and make a decision of how well we think he did the work.
G.1. I.1.c.	Focusing Design of study		What was his next step after he stated the problem?
		S.	After he stated the problem, he went right into the design of the experiment.
M.2.	Invite more thinking	T.	Are you saying that he did not have a hypothesis?
		S.	Yes.
G.2.	Extending	T.	How do the rest of you feel about this? Were you able to find a hypothesis?

		S.	Well I don't believe he had a hypothesis either, because he didn't know what he would get after he crossed those, so I couldn't see how he could have one.
M.1. G.1. I.3.	Support Focusing Evaluation of report	T.	So he just sort of worked inductively. He stated the problem, and then he sat down to start solving it. Do you think this a valid way for a scientist to work? Now that we understand the way Mendel did this, do you think this was a valid approach?

(*Note:* A series of lead-up questions might have helped student to respond to teacher's evaluative question.)

		S.	I don't believe he had a hypothesis because, to form a hypothesis, you must have some guidelines to go by to know if your ideas are right. If you just jump in headlong, you won't know what kind of results you need to get. You can't look back on your results and get an explanation for them.
M.1. M.2.	Support Invite more thinking	T.	All right, you've brought up something there that is interesting. You said he jumped in sort of headlong. Do you think Mendel is guilty of this?
		S.	Well, he kind of had everything planned out; he knew what problem he was working on. Since he didn't have a hypothesis, he didn't have any idea what he was going to get.
M.2.	Invite more thinking	T.	Do you really think that he didn't have any idea of what he was going to get? I'd like to hear from this young lady.
		S.	Well, I think that he was pretty sure he would find a law.
M.1.	Support	T.	He states in two or three places that he's looking for a law of order by which these characteristics are transmitted from one generation to another,

	specifically dealing with hybrid forms. You've already quoted from two places in the paper in which this is stated or implied.
G.1. Focusing I.2.d. Assumptions *re* problem	What assumptions did he make in regard to this? Did you pick up some of that?
	S. Well, where he stated the part about finding a generally applicable law. I think he must have assumed there is a law.
M.1. Support G.1. Focusing I.2.e. Relation between design of study and problem	T. He assumes that there is a law. Now let me refer you to page 2 of the paper, under "Selection of Experimental Plants." "The selection of the plant group which shall serve for experiments of this kind must be made with all possible care if it is to be desired to avoid from the outset every risk of questionable results." Then it goes through three of the necessary qualifications of the plants. Why was it necessary for him to have plants that possessed constant differentiating characteristics? Why do you suppose he made this a prerequisite?
	S. Because if he didn't have plants that were constant, he wouldn't know what changed in the plants during the experiments.
	S. He would have had no control.
M.2. Invite more thinking	T. All right, did Mendel have a control in the work he was doing?
	S. Well, he put some kinds in a greenhouse, and that could be a control because the rest of them were outdoors, and he said if there was anything, if the insects bothered them (he didn't think they'd bother them very much, but if they did) he could tell what the insects did because he had some more in the greenhouse.

M.1. Support M.3. Refocusing	T. That was a control for insects, wasn't it? Did he also have control for the way the characteristics were transmitted from one generation to the next as he was doing the experiment? Did he control the genetics?
	S. Well, he only had one variable in each plant.
M.2. Invite more thinking	T. How did he know that these plants were different?
	S. He observed the plants two years before he crossed them.
M.1. Support	T. So, in this case he could control the experiment before he started in as far as the characteristics of the plants are concerned.
G.1. Focusing I.1.c. Design of study	Let's read number 2, on page 2: "The hybrids of said plants must, during the flowering period, be protected from the influence of all foreign pollen, or be easily capable of said protection." Why was this necessary? I think we brought this out before, but let's be sure it's clear to all of us. Let's see, I'm hearing from one, two, three, four, five, six people.
	S. Would you repeat the question?
	T. It refers to number 2 under "Selection of Experimental Plants."
	S. He had to know what pollen entered what plants and fertilized them.
M.2. Invite more thinking	T. Why is that important?
	S. Because otherwise he wouldn't know which plants were the parents.
G.2. Extending I.1.c. Design of study	T. Let's go on and look at the third prerequisite: "the hybrids and their offspring . . ." (I'm reading under number 2) "the hybrids and their offspring should suffer no marks of disturbance in their fertility in successive generations." Why was this a prerequisite?

	S. Well, if they couldn't produce offspring, then they couldn't go any further.
M.1. Support	T. All right, he couldn't find out what happened as far as the offspring are concerned. So he sets the criteria for the selection of the experimental plants. Now we've taken a look at the problem and we have said that there isn't really a hypothesis, but yet he's very careful about how he selects the experimental plants. He raises these plants for two years before he starts to do the crossing – that is, the crossing between the parental plants used in the experiments. We mentioned he may have jumped into this headlong, and I think we've decided that that was probably not the case, since he set up those criteria and he raised the plants for two years before starting the experimental crosses.
G.1. Focusing I.1.f. Identification of assumptions	Now, did you pick up any assumptions that perhaps he was working with?
	S. I have a question. How could he tell the pea plants have the necessary characteristics?
M.2. Invite more thinking	T. How do you suppose he did this?
	S. Well, when he raised the pure-breeding plants for two years, he could have crossed them during that time, or before, to see if they have fertile offspring.
M.2. Invite more thinking	T. Are you saying that he may have done some things without listing them in his report?
	S. He may have decided that without telling you anything about it.
M.1. Support	T. All right, don't you think that at one time or another he crossed some of these pea plants to see if they would have fertile offspring? Is it likely that he would've done that sort of thing? Because, if

you read on farther here, he mentioned the fact that the pea plants do meet the requirements; on page 3, the second full paragraph down, "Some thoroughly distinct forms of this genus possess characters which are constant, and easily and certainly recognizable, and when their hybrids are mutually crossed they yield perfectly fertile progeny."

M.3. Refocusing — What assumptions can we make from that?

S. That he experimented with them.

S. Or the work of other plant breeders had shown that these were characteristics of pea plants.

M.3. Refocusing
I.2.d. Assumptions *re* design of study

T: Back on our line of thinking then, can you think of some assumptions that he was making when he stated the problem, and when he set about to find plants that fill the criteria? It seems to me that he's saying more than, "Well, I'm going to select out certain plants which meet any requirements that I want to put down on paper." What assumptions did he make that guided the fact that he had to have plants that met certain requirements?

(*Note:* In this case the refocusing is necessary because the initial focusing question did not make clear the type of assumptions to be identified.)

S. One of his assumptions was that these three qualities in plants were necessary to follow a certain characteristic from parents to offspring. He also assumed that there must be some kind of plant which would meet the three conditions.

M.1. Support

T. Let's go back and look at the problem again. The object of the experiment was to observe these variations in the case of each pair of differentiating characteristics and deduce the law according to

	which they appeared in successive generations. So you're saying that the assumptions, then, for the type of plants that he had to have, related back to the problem.
G.1. Focusing I.1.c. Design of study	T. Now, how is he going about solving the problem? Let me ask you this. What was Mendel going to do that was not done before his time? What was he going to do that was different? Now he gives you some idea of what's been done before, in the introduction, and sort of looks at this and says, "Ah, they've done that, now I'm going to do something else." Did you pick up what he was going to do differently?
	S. He is going to differ in that he is going to try to figure out some kind of relationship, sort of a ratio, to correspond to what other people had described verbally.
G.2. Extending	T. How is he going to find a ratio? What kind of data is he going to get? What kind of data is he looking for in relation to the problem – that reflects what he's going to do differently?
	S. Before when they experimented they used all different kinds – they were different with a whole lot of different characteristics. He was going to use one that was different from another in only one characteristic, then he was going to show how it worked out.
M.3. Refocusing	T. A minute ago you used the term "ratio;" how is he going to find the ratio? What's he going to do?
	S. Interpret his data mathematically.
M.1. Support G.2. Extending	T. Good. And what must he do in order to interpret his data mathematically? *(long pause)*

		I'd like to direct your attention to the top of page 2, ". . . to make it possible to determine the number of different forms under which the offspring of hybrids appear, or to arrange these forms with certainty according to their separate generations, or definitely to ascertain their statistical relations." What does he plan to do? What must he do in order to carry this out?
	S.	He has to keep track of the characteristics in each generation.
	S.	Before that he says he's going to make sure he can tell the different forms of the offspring of the hybrids.
	S.	If he's going to determine statistical relations, he's going to have to count the different types.
M.1. Support	T.	Very good. In other words, he's going to have to count the types he gets in each generation and he's going to interpret his data mathematically, statistically. He's going to collect *quantitative* data and make his inferences from that. As far as we know, he was the first one to do this.
G.1. Focusing I.1.c. Design of study	T.	All right, what plan did he use? How did he go about it? What did he do?
		(long pause)
		Well, we've had some time to think about this.
	S.	He picked peas with seven different characteristics.
G.2. Extending	T.	Let's enlarge on this; he picked peas with seven different characteristics. Maybe we can diagram this on the board. Can you help me young lady? What do you think is the first thing I should put up here?
	S.	Selection of plants.

M.1. M.2.	Support Invite more thinking	T.	Can you add something to what we've already said on selection of plants? This was his first step I guess, wasn't it?
		S.	He used true hybrids.
M.2.	Invite more thinking	T.	I'm a little confused because usually when you breed a hybrid plant you get different kinds of off-spring from it. Now, what do you mean by true hybrids?
		S.	He used pure breeding plants.
M.1.	Support	T.	Very good.
		S.	Well, how come the plants that he chose were peas? Were they best suited for the experiments, or, say, why didn't he use beans, or tomato plants?

(*Note:* Even though student here asks a question which takes the discussion off the track set by the teacher, and back to an aspect of the report already dealt with, the teacher continues on the line set by this student on through the next page until it is cleared up and they can return to the design and execution of the study.)

M.1.	Support	T.	All right, do you have any ideas? That is an excel-lent question, I've wondered about that several times myself. Why in the world would he choose pea plants?
		S.	Well, one big reason was that they couldn't be fertilized by insects.
M.1. G.2.	Support Extending	T.	All right, this is one thing. What else?
		S.	Size, rate of growth, a pea plant will grow straight up – a tomato plant will get all drawn out and everything where a pea plant forms a nice vine.
		S.	Well, in the paper it said that artificial fertilization was one of the reasons.
M.1.	Support	T.	All right, and this goes back to closed flowers; if you're going to artificially fertilize the plants, you've got to protect the top of the ovary and the stigma from foreign pollen.

	S. It says in the paper that they also have a short life time.
M.1. Support G.2. Extending	T. The availability of different varieties is another factor. Do you have some other ideas?
	S. Well, you can get a lot of peas from one generation.
M.1. Support	T. All right, in other words pea plants typically have many flowers, form many pods, and all the other things you've mentioned. There's one other thing I might add, that I think someone touched upon earlier, is just the fact that they were available. Remember, in the paper, when he talks about getting the seeds. They were available; it was something he could work with that seemed to fit all the criteria, and had the other advantages you've mentioned as well.
G.1. Focusing I.1.d. Execution of the plan	Now, what's the next item I should put up here? Or maybe you want to change something that's up here? We're trying to look now at how he went about solving his problem, how he carried out his experiments.
	S. He found a number of weak plants and selected only vigorous plants.
M.1. Support M.2. Invite more thinking	T. Okay. He selected only the vigorous plants. Wonder why he did that? Isn't this kind of going against being scientific?
	S. Well, he wanted to find differences between plants. If he didn't choose the most vigorous plant, it would cause him difficulty in determining kinds of plants or kinds of offspring.
(End of first session)	
G.1. Focusing (review) I.1.a. Identification of problem	T. Yesterday we talked about the problem, assumptions, and some about the experimental design. By

		experimental design we mean what plan was used to answer the question. Do you recall the question he's working with? Maybe we can restate it and go on. What question was he working with? Can some-one restate it for us today?
	S.	Shall I read the paper?
M.1. Support	T.	If you would, please.
	S.	"The object of the experiment was to observe these variations in the case of each pair of differ-entiating characteristics and to deduce the law in which they appear in successive generations."
G.1. Focusing I.1.c. Design of study	T.	Now how did he go about to answer that particular question?
	S.	He selected plants.
M.2. Invite more thinking	T.	All right, selected plants. Just any plants?
	S.	Vigorous.
G.2. Extending	T.	Vigorous plants. What other criteria did he use?
	S.	True-breeding plants.
M.1. Support G.2. Extending	T.	All right, true-breeding plants. What other criteria did he use? Is this all he did was find true-breeding plants? Yes?
	S.	He chose plants that were self-pollinating.
G.2. Extending	T.	All right, self-pollinating. Any other characteristics? Yes?
	S.	He used plants that were pollinated by themselves.
M.1. Support G.2. Extending	T.	Well, that's kind of self-pollination. We're really talking about the characteristics of the flower of the plant, aren't we? What characteristics did he require that the plants have? If you'll think back to the paper, I think you'll recall two or three criteria of what the plants must have. Yes?

	S.	That plants possess constant differentiating characteristics.
M.1. Support G.2. Extending	T.	All right, constant differentiating characteristics. I think we talked some about why, and what that is, yesterday. What else?
	S.	He wanted the flowers to be closed, so foreign pollen could not get in.
	T.	And thirdly . . .
M.1. Support	T.	Will you speak up, please, I can't quite hear you.
	S.	He wanted the offspring to suffer no marked disturbance in their fertility.
G.1. Focusing I.1.d. Execution of plan	T.	Let's go on. What did he do next as far as the plan he followed to answer the problem? He selected the plants according to certain criteria. What did he do then?
	S.	He selected an area in which to grow them.
M.2. Invite more thinking	T.	Where did he grow them, did he tell you?
	S.	In the garden.
M.1. Support M.3. Refocusing	T.	In the graden and, as we also said yesterday, some of them in the greenhouse. Let's go on; what did he do next? Is this all he did, select the plants and the area where they should be grown?
	S.	He had to choose the traits on the plants.
M.1. Support G.2. Extending	T.	Fine, he chose the traits didn't he? Maybe we can have a couple of examples of those. Could someone read us the first example he gives?
	S.	The difference in the form of ripe seeds.
M.1. Support	T.	The difference in the form of ripe seeds. Another one, the next one listed, is the color of the seed albumen or the endosperm. It stores food. So he chose the traits.

G.2.	Extending	T.	How many traits did he have for each character?
		S.	Well for each plant he had just one, but he had seven characters.
M.2.	Invite more thinking	T.	Could you give us an example of a trait and a character?
		S.	A trait would be like round or wrinkled, and the character would be the shape.
M.1.	Support	T.	So each plant had one trait, and he had plants with opposing traits for each character.
G.3.	Refocusing		Now, what was the next step?
		S.	He set up his control.
M.1. M.2.	Support Invite more thinking	T.	Set up his control. What do the rest of you think about this? Did he set up controls at this stage?

(*Note:* Directing the question to other students implies a negative comment, M.4., on the part of the teacher, but from an audio tape it is difficult to determine if the student perceived it that way.)

		S.	He had taken two years of trial working with pea plants, so he had a control earlier before he started crossing.
M.1.	Support	T.	I think what we're saying is that he controlled it all right, but before he started the experimental crosses.
M.3.	Refocusing	T.	You're going to have to help me along here. I'm sure you've worked through experimental designs before, ways that investigators have gone about solving problems. What's the next step? What will he do? How did he go about solving the problem?
		S.	Well, then he bred plants with the same traits.
M.1. M.2.	Support Invite more thinking	T.	All right, bred plants with the same traits. Could you give us an example of this from the paper?
		S.	He crossed two plants that had round seeds.
M.1.	Support	T.	He crossed two plants that had round seeds.
		S.	No, I mean plants with round and wrinkled seeds.

M.1. Support G.2. Extend	T.	Okay, plants with round seeds and plants with wrinkled seeds. Any comment on this? Yes?
	S.	Well, didn't he cross plants with round seeds?
M.4. Negative (very mildly so)	T.	Did he cross round with round? Let me see. We're saying that round was crossed with wrinkled. Now are you questioning this?
	S.	Well, I thought yesterday we said he was going to cross . . . Oh, well, never mind.
M.1. Support	T.	This I think was the point we tried to make awhile ago when we were talking about two different traits that have to do with the same thing – the shape of the seed as being one particular characteristic. Now, there's two shapes that we're dealing with – round and wrinkled. Because the one character here is the shape of the seed. Are you clear?
	S.	Uh-huh.
M.3. Refocusing	T.	All right, the next step he used in solving the problem – What was the procedure that he followed?
	S.	In every one of his crosses, he used reciprocal crosses.
M.1. Support G.2. Extending	T.	Good. Why do you suppose he did this? Why would he use reciprocal crossing?
	S.	He would be able to get data to see if the egg and sperm contribute equally to the uh – character.
	T.	All right.
	S.	Well, I think he might have done it to find out if they do contribute equally.
M.1. Support	T.	He might've done it to find out if they do contribute equally to the character. Do you suppose Mendel knew about chromosomes? He was really working under a kind of difficulty because the

		things that you know were completely unknown to him.
G.1. Focusing I.1.e. Interpretation of data		What did he find? Do they or don't they contribute equally?
	S.	They do.
M.2. Invite more thinking	T.	Can you explain that for us? How did Mendel determine that? What was the basis for that interpretation?

(*Note:* Asking three questions that call for different things might confuse the student.)

	S.	Because he couldn't find any differences between the results of the two (reciprocal) crossings.
M.1. Support M.3. Refocusing	T.	Very good. Now, what was the next step? What did he do – the next step in the procedure?
	S.	He started crossing with all the different characters that were given, and he would formulate his data after he did that.
M.2. Invite more thinking	T.	Good. Let's see if we're all clear on what you said – you included a lot in that statement. What crosses did he make with all the different characters?
	S.	He crossed each pair of traits for each character – like yellow and green endosperm.
M.2. Invite more thinking	T.	And what data did he get? What were the results when he did the crossing?
	S.	Just one of the traits of the parent plants showed in the offspring – the dominant one.
G.1. Focusing I.1.e. Interpretation of data	T.	Let's diagram some of this as we go along. Let's concentrate on the round and wrinkled. Even though he used seven characters, let's follow just one. All right, we think of this as his first cross. Now we can label each generation as follows: This is the parental generation, sometimes called *P*; this is the first generation, the one Mendel called the

			hybrids, or F_1. How about ratios? Does he give you some numbers on this? Someone said earlier that he was going to count them – can you find any numbers that he worked with?
		S.	Oh – well, on the F_2 he got, well when he used 565, 192 were round and 372 were both wrinkled and round.
M.2.	Invite more thinking	T.	All right, now what page is that on?
		S.	I don't know what page it is on; it's in my notes . . . It's on page 12.
M.1. M.3.	Support Refocusing	T.	Okay, that gives us part of the data on the F_3 generation. Let's go back to the F_1 generation. What did he get in the first generation?
		S.	All one kind of trait for each character.
G.2.	Extending	T.	All right, what did he do next?
		S.	He crossed the F_1 generation.
M.1. M.2.	Support Invite more thinking	T.	All right, he crossed the F_1 generation. What did he cross them with?
		S.	Crossed them with themselves.
M.3.	Refocusing	T.	All right, then this would give him the F_2. What kind of results did he get?
		S.	Some were round and some were wrinkled.
M.2.	Invite more thinking	T.	All right, some were round and some were wrinkled. I think we've got some data to work with here, haven't we? There are some specific numbers. Would somebody be kind enough to give those to us?
		S.	"From 253 hybrids, 7,324 seeds were obtained in the second trial year. Among them were 5,474 round or roundish ones and 1,850 angular wrinkled ones."

M.2. Invite more thinking	T.	What about his ratio here? It's 2.96 to 1. Is the ratio close enough to 3 to 1 to call it that?
	S.	Well, how come he has a ratio of 2.96 to 1? Shouldn't it be 2.96 to 1.04? Shouldn't it add up to one?
M.3. Refocusing	T.	I really can't answer that because all I have is the record. It goes on in the paper and sums up the F_2 generation. Is there anything you would like to question about things found on pages 10 and 11?
	S.	What does he mean by a character having double signification?
M.1. Support M.3. Refocusing	T.	All right. "The dominant character can have a double signification – that of a parental character or a hybrid-character. In which of the two significations it appears in each separate case can only be determined by the following generation." What does he mean here? Do you have some idea of what he's talking about? He's talking about the dominant character now, in our example those seeds which are round. Remember we said he got a 2.96 to 1 ratio which he rounded off to a 3 to 1 ratio. Do you have some idea what the double signification means?
	S.	The ones that come from pure hybrid parents can have two characters – one like the first parent or one like the second parent.
M.2. Invite more thinking	T.	Sally, I'm not sure I know what you mean. Maybe you could clarify that for us.
	S.	The seeds that come from the hybrid will be some round and some wrinkled – like the original parents.
	S.	I thought by hybrid-character it would be the ones that are heterozygous.

M.1. Support	T.	Good – both of you are correct. But "heterozygous" is a more recent term for what Mendel meant by "hybrid-character." He didn't use the term "heterozygous." What does Mendel mean by "parental character?"
		(long pause)
		I guess a good question here is, if you are looking at the round seed, can you determine by looking at it what its genotype is? What did he have to do in order to determine the genotype of those seeds?
	S.	He had to cross them.
M.2. Invite more thinking	T.	What did he cross them with?
	S.	Some just like them.
M.1. Support	T.	All right, some that were just like them, or let the plants self-pollinate. What kinds of seeds resulted from this self-pollination? What generation do we have to look at?
	S.	The F_3.
	T.	Look at page 12, the second paragraph under the heading. What does that paragraph mean?
	S.	It means some round seeds produce both round and wrinkled. Therefore, even though they are round they carry some kind of genetic make-up that allows them to produce wrinkled seeds. Other round seeds produce only round.
	S.	I don't understand – if he had a plant that had a trait that had a genotype that was heterozygous, why would you cross it with one that was the same thing? You'd still get homozygous or heterozygous. So then how could you tell if it was homozygous or heterozygous in the first place?
M.2. Invite more thinking	T.	Can some of the rest of you answer this?

S. If they were heterozygous and crossed with themselves, the offspring would be of different kinds. If homozygous, they would all be the same.

T. Let's see how Mendel states it. Look at the bottom of page 11 and top of page 12: "The dominant character can have a double signification – that of a parental character or a hybrid-character. In which of the two significations it appears in each separate case can only be determined by the following generation. As a parental character it must pass over unchanged to the whole of the offspring; as a hybrid-character, on the other hand, it must maintain the same behavior as in the first generation." Now is it clear what "double signification of the dominant character" means?

M.3. Refocusing

T. Now we will have to look at this next part very carefully because we will be talking about ratios, and we will jump from a 3 to 1 ratio to a 2 to 1 ratio. Now let's try to interpret this. What kind of results did he get? Let's see if we can really analyze this out. Now we are talking about the F_3 generation. What kind of data did he get?

S. "Experiment 1. Among 565 plants which were raised from round seeds of the first generation, 193 yielded round seeds only, and remained therefore constant in this character; 372, however, gave both round and wrinkled seeds, in the proportion of 3 to 1. The number of the hybrids, therefore, as compared with the constants is 1.93 to 1."
(Teacher repeats results of Experiment 1 while writing it on the chalk board.)

G.1. Focusing
I.1.e. Interpretation

T. Do you follow that?
Well, let's go on. How does he organize his data?

	Would you have done it differently if you were writing that – other than using different words? Do you think that he presented his data in a well-organized way? The best way, perhaps, that he could?
	S. It seems like he didn't have any separate place for his data. He would just throw it in here and throw it in there . . . I think that he should have made a special little part for his data and referred back to that.
M.2. Invite more thinking	T. How was his data organized? We touched on that, I think. How did he organize his data throughout the paper?
	S. Sometimes he used tables, but most of the time it is scattered throughout the paper.
G.1. Focusing I.1.e. Interpretation of data	T. Well, let's look at his conclusions. What conclusions did he make? Will you read it for us, what you believe to be the conclusion?
	S. "Since the members of the first generation (F_2) spring directly from the seed of the hybrids (F_1), it is now clear that the hybrids form seeds having one or other of the two differentiating characters, and of these one-half develop again the hybrid form, while the other half yield plants which remain constant and receive the dominant or the recessive characters (respectively) in equal numbers."
G.1. Focusing I.2.b. Relation between interpretation and data	T. Do you think that his conclusion is valid, based upon the data that he got? Do you have any question about this?
	S. His conclusion is only applicable to pea plants, you know.
M.2. Invite more thinking	T. Does he indicate anywhere in the paper that it would work for something other than peas?

	S. Well in the introduction he states so far no generally applicable law has been formulated.
G.2. Extending	T. Do you think that that is the case? Do you think . . . Keep questioning. I would like to know what you think about that.
	S. Well, if he would have compared his results with other kinds of plants – uh, he would have more nearly had a generally applicable law – uh, he also should have tried more crosses.
G.1. Focusing I.1.3. Evaluation of report	T. Are there some general comments you would like to make about the paper? I have been sort of leading you along and directing you. I would like to give you a chance now to make some general comments about the paper and how you feel about it.
	S. I would like to go back to, well, just before Carl said that he thought that data should be placed on a separate sheet or separate table. I kind of felt that, I mean, in his time and everything, I think the data as it was, was fine because he sets up what he is going to do, and each time he interprets it for you before he does it and tells you exactly what he is going to do, and then he goes right into his data and formulates his data and everything, and it's right there for you. You don't have to refer back and forth. I mean, maybe now it might be better to do it differently, but I just think it is the way it should be done.
M.1. Support M.2. Invite more thinking	T. In general, how would you describe the way he organized it? I think you are getting it here, I would just like to have you repeat that. How did he organize it?

S. Well, he set up his interpretation first and told what the experiment was going to be and what he was going to do . . . and he gave us everything he was using and then he went ahead and did the experiment, formulated his data, and put it right below his interpretation so you got exactly what he did out of it.

S. I think it's good that he wrote it out because people weren't exactly mathematically inclined, therefore, it would be easier for them to read and understand.

APPENDIX A

INTERIM SUMMARIES OF INVITATIONS TO ENQUIRY FROM THE BSCS *BIOLOGY TEACHERS' HANDBOOK*

ACKNOWLEDGEMENTS

The writing committee gratefully acknowledges its reliance on a concept of enquiry[1] developed by Joseph J. Schwab. One version of this concept is presented in this Appendix. See also bibliography numbers 62, 112, and 137 (pp. 124, 132 and 137 respectively).

The Interim Summaries, presented in the following pages, are integral parts of Chapter Four of the BSCS *Biology Teachers' Handbook* (in both the 1963 and 1970 editions) and are best understood by reading the Invitations and Interim Summaries in the sequence as presented in the *Handbook*. We are listing the Invitations here rather than presenting them in their entirety simply because of the total number of pages involved. The material in this Appendix is presented with the permission of the Biological Sciences Curriculum Study, P.O. Box 930, Boulder, Colorado.

[1] While much of what is included in Chapters Two, Three, and Six is either based on or related to Schwab's work, the writing committee has chosen the more common spelling of "inquiry."

TABLE OF CONTENTS

THE NATURE AND USE OF INVITATIONS TO ENQUIRY[2]

The Invitations to Enquiry are teaching units that provide the student with samples of the operation of the process of Enquiry. Omissions may include, among other things, the plan of an experiment or the conclusions to be drawn from given data. The student is invited to participate actively in the enquiry and thus contribute to his own understanding of how science operates.

The Invitations include separate components for teachers and students. Suggestions and explanations are provided to aid the teacher in mapping and guiding each enquiry discussion. The materials invite contributions from students as they engage in a discussion with the teacher or each other. Many of the Invitations are sequenced so that they tend to build on one another and deal with a continuing problem, not isolated parts of a problem.

The Invitations are grouped largely on the basis of five general principles or concepts for guiding inquiry (see Chapter Two). These guiding principles and their underlying assumptions are discussed in the Interim Summaries and recapitulate the concepts developed in the Invitations.

[2]A more extensive statement of the nature and use of Invitations to Enquiry may be found in Schwab (137), Chapter Four (1963 and 1970 editions).

INVITATIONS TO ENQUIRY, GROUP I

Simple Enquiry: The Role and Nature of General Knowledge, Data, Experiment, Control, Hypothesis, and Problem in Scientific Investigation

LIST OF INVITATIONS (1-4)

Invitation	Subject	Topic
1	The cell nucleus	Interpretation of simple data
2	The cell nucleus	Interpretation of variable data
3	Seed germination	Misinterpretation of data
4	Plant physiology	Interpretation of complex data

Interim Summary 1

Knowledge and Data[3]

THE IDEA OF GENERAL KNOWLEDGE

With Invitation 4 we have completed our introduction to the student of simple enquiry. In this introduction, we have tried to show him the operation of two ideas basic to the scientific enterprise. Let us review these ideas briefly and at the same time note certain relations among them.

One idea is central to all others in defining the scientific enterprise. It is the idea of *general* knowledge, knowledge which is not about one particular thing in one particular time and place but knowledge which embraces whole sets of particulars. This idea sets science apart from almost all the other forms of knowledge and enquiry man has invented. History and biography, for example, are dedicated to the particular. Generally, they try to recover and recount specific, unique events, each occurring at a specified time and place—in a certain city on a certain day, or in the mind of a certain leader or thinker in the midst of a specified, single moment of thought or decision. Rarely, indeed, does the historian try to discover general laws among his particulars. And when he does, he is quite ready, nay, proud to say that what he is trying to write is *scientific* history.

The idea of general truths about particulars also sets science apart from mathematics—although in an entirely different way from that which distinguishes science from history. Mathematics is as general as science; perhaps, indeed, much more general, even universal. What geometry has to say about "triangle," for example, holds for all triangles and has bearing on all other figures as well.

Nevertheless, the generality of mathematics does not make it the same as science, for the general knowledge characteristic of science is general knowledge of concrete, existing, observable, measurable particulars. It is about the world of things and events. The knowledge of mathematics is not derived from the world of things and events. The general or universal statements of the mathematician have their origin in something else—perhaps in ideas in the mind of the mathematician, ideas which he studies and whose component ideas become the content of his theorems. Men are divided, in fact, about the nature and origin of mathematics, but one thing is clear; whatever the origin of mathematics may be, it is not an origin in concrete, existing, observable, measurable particulars. The Pythagorean theorem, in its mathematical form, did not arise *from* measurements of the sides of many triangles.

The essence of science, then, is that it is, paradoxically, *general* knowledge from *particulars*, from existing, observable, measurable particulars belonging to the world of things and events.

THE IDEA OF DATA

Science, then, begins with particulars, but it does not rest in them. Particulars are indispensable to science, but only as raw materials. Further, they are indispensable raw materials of a certain limited kind. They are like ore to the refiner of metals. Some of the ore is unwanted material. Only a part of it is the desired gold. So, too, with particulars as the ore of science. Only *some* aspects and items of a group of particulars are relevant and useful to a scientist in search of a general truth. The remainder of the manifold aspects of the particulars are irrelevant to his search.

Only *some* aspects, then, of a group of particulars serve as raw materials for any one general truth. It is this condition that defines what we mean by scientific *data*. Data are the gold extracted from the ore. They represent the facts about particulars that the scientist selects from all the available facts because he thinks they will best serve the aim of science—lead him to the most revealing truths about the particulars he is studying. *Data*, then, are *selected facts*.

Our Invitations (1 and 2) begin with this point. A scientist wants to know about the role of nuclei in cells. He selects the facts which are relevant to this question. He examines these selected facts, these data, and tries to draw from them (*interprets* them) a general truth about cells and nuclei. Note how the major points we have mentioned are involved in these beginning hints about enquiry. First, the data are "real"; they represent the facts. Second, the data represent selected facts; they are only those facts that will answer the question about the nucleus which the scientist has formulated as the central portion of the problem. Third, the data are only raw materials, starting points. What the scientist can *make* of his data is the climax of his enterprise.

[3]Interim summaries in the Appendix are reproduced from Schwab, J. J. (Supervisor) BSCS *Biology Teachers' Handbook*. New York: John Wiley, 1963. 2nd Edition, 1970. Klinckmann, E. (Supervisor).

LIST OF INVITATIONS (5-13)

Invitation	Subject	Topic
5	Measurement in general	Systematic and random error
6	Plant nutrition	Planning of experiment
7	Plant nutrition	Control of experiment
8	Predator-prey; natural populations	"Second-best" data
9	Population growth	The problem of sampling
10	Environment and disease	The idea of hypothesis
11	Light and plant growth	Construction of hypotheses
12	Vitamin deficiency	"If . . ., then . . . ." analysis
13	Natural selection	Practice in hypothesis

Interim Summary 2

The Role of Hypothesis

EXPERIMENT AND CONTROL

Invitations 1 to 4 emphasized only the ideas of *data* and *general knowledge*. Their relations were summed up in Interim Summary 1. Data (selected facts) are the raw materials of science. What the scientist can *make* of his data is the climax of the enterprise.

In Invitation 2 we began to hint at some of the difficulties the scientist faces in this enterprise. It was pointed out there that data rarely come "clean"; they always involve variability, which the scientist must somehow cut through in order to arrive at general knowledge. On the whole, however, these early Invitations were confined to exemplifying the use of data in arriving at general knowledge.

The theme of Invitations 5 through 13, on the other hand, is the problem of obtaining wanted data. Let us look back briefly at the order in which different aspects of this problem were raised. Invitation 5 points out the existence of *error* and the fact that it can be reduced but not eliminated. Invitation 6 then introduces *experiment* as the means, *par excellence,* for obtaining our chosen data. Experiment is defined as a situation so planned as to yield specified, wanted data. However, the difficulties in the way of *carrying out* the plan of an experiment are not dealt with here but carried over to Invitation 7. Here again the emphasis is on the difficulty of obtaining wanted data, the particular difficulty being that of ensuring adequate *control.*

OPERATIONAL UNCERTAINTY IN SCIENCE

Invitation 8 raises a quite different aspect of the problem of obtaining wanted data. In an ecological setting we see the possibility that the operations required to obtain one set of wanted data may so warp the situation under investigation that little further useful data can be obtained. This kind of handicap to the progress of enquiry is of considerable importance. It arises whenever we are investigating a sequence of events in time. In such a case, we usually require data about the progress of the sequence—what it is like from moment to moment. This requirement often leads, in turn, to the need for intruding ourselves or our instruments into the process under investigation. By this act we may so alter the process that its further behavior is no longer appropriate to our investigation.

One of the most extreme examples of this problem occurs in those investigations in the physical sciences where the objects under investigation are very small. In such cases, the most refined methods of measurement must use devices of much the same size as the objects investigated. How are we, for example, to measure the velocity of an electron without using something *on* the electron that is as big or bigger than it is, and that therefore alters the velocity to a degree which may make the measurement worthless for our purposes?

The most extreme examples of this handicap may occur only in small-particle physics, but it is, nevertheless, a continuing problem in biology, too. It arises in the experimental study of the developing embryo, in the experimental study of growing and waning populations, in the experimental study of population genetics and evolution, and so on. It is illustrated once again among our enquiries in the case of Invitation 9, where the problem of sampling a mouse population is not merely a problem of obtaining a fair sample but also a problem of minimizing the effect of sampling on the population itself.

THE ROLE OF HYPOTHESES IN SCIENCE

Invitations 10 and 11 continue to treat the problem of obtaining wanted data. They introduce the idea of *hypothesis* in close connection with the use of "If . . . , then . . ." reasoning.

In these Invitations the hypothesis is treated in large part as if its

role in science was primarily to be established or disestablished, "proved" or "disproved." In fact, however, hypotheses play another important role. They serve as guides pointing the way to new discoveries.

We can make the significance of this role clearer by re-examining the "If . . . , then . . ." logic associated with the use of hypotheses. When we look at such a logical chain from one point of view, it seems to be purely and simply a major step toward "proving" the "If." "If *A*, then *B*." We seek for *B*. If we find it, our hypothesis, *A*, is rendered possible. If we fail to find *B*, we are in doubt. If we show that *B* does not exist, we have disproved the hypothesis, *A*.

Now let us look at an "If *A*, then *B*" from another point of view. The *A*, the hypothesis, is a new idea, or a familiar idea in an untried and unfamiliar context. Therefore, the *B* is also something new or something familiar but located in a context as yet unsearched; so we proceed to search for the new thing or in the new context. In this new search *something* new may be discovered. Whether the something new corresponds to our hypothesis or not, it sets off a stream of fresh enquiries likely to lead to fresh and important knowledge. This is the point suggested in Invitation 11 and repeated in Invitations 12 and 13.

There are two important ways to emphasize this role of hypotheses. One way is to point out that science is not one process but two. It is a process of discovery as well as a process of "proof."

A second important way to present the role of hypotheses in the process of discovery is as follows. The problem of obtaining wanted data is twofold. First, it is the problem of obtaining the data when we know what data we want. The planned and controlled experiment is the best solution to this problem.

In addition, the problem of obtaining wanted data is the problem of *knowing what data to want.* The conceiving of fresh hypotheses is the way we solve this problem.

The two problems are, of course, connected. Hence the devices that solve them are connected too. Although it is the experiment that leads us to our data, it is the hypothesis that leads us to our experiment. And the fresh hypothesis leads us also to fresh problems.

LIST OF INVITATIONS (14-16A)

Invitation	Subject	Topic
14	Auxins and plant movement	Hypothesis; interpretation of abnormality
15	Neurohormones of the heart	Origin of scientific problems
16	Discovery of penicillin	Accident in enquiry
16A	Dicovery of anaphylaxis	Accident in enquiry

INVITATIONS TO ENQUIRY, GROUP II

The Conception of Cause in Biological Enquiry: Causal Factors, Multiple Causes, Time Sequences, Negative Causation, Feedback

LIST OF INVITATIONS (17-25)

Invitations	Subject	Topic
17	Thyroid action	Unit causes
18	Disease and treatment	Unit causes
19	Photosynthesis	Serial causation
20	Several examples of sequential analysis	Serial causation
21	Parathyroid action	Multiple causation
22	Control of pancreas	Diverse causation
23	Control of pancreas, continued	Diverse effects of diverse causes
24	Control of thyroid secretion	Inhibitory causes
25	Pituitary-gonad mechanism	Feedback mechanisms

Interim Summary 3

The Concept of Causal Lines

The Invitations up to this point *seem* to present a reasonably complete conception of scientific research. We have dealt with the ideas of data and their interpretation, the planning of experiments, the construction of hypotheses, the formation of problems, and the search for causal factors.

In fact, however, these Invitations represent only one pattern of enquiry used in biological research, a pattern based on the conception of independent causal lines. In later Invitations, we deal with other patterns—the pattern based on the idea of *function* and the pattern based on the idea of *regulation*. Before embarking on these, and in order to begin to clarify the differences among these lines of biological enquiry, let us look back at the idea of separate causal lines.

The idea of separate causal lines is one of the simplest but also one of the most useful principles of enquiry used in science. Basically, the idea is that we treat any given whole *as if* it consists of many separate parts, each of which operates as a separate, *independent* entity. That is, we plan experiments and interpret data as if what each part *is* and *does*, it *is* and *does* regardless of the company it keeps and regardless of whether it keeps company or not. Each part is considered independent in the sense that we treat it as if its behavior and effect are always the same whether the other parts act or not.

The advantage of such a principle of enquiry is that it lets us study a given subject matter by studying each of its parts without worry about connections between the studied part and other parts. If we assume that each part operates as if it is independent, we can ignore the company it keeps or even remove it from the complicated company it keeps and study its properties and behavior when alone—which is much simpler and less confusing than studying it when it is working as a part in the larger whole.

Conversely, the assumption of independent parts and separate causal lines lets us remove a part from the whole and treat the remainder of the whole as if none of the remaining parts had been affected by the removal of the one part in question. As so many of our previous Invitations have indicated, the assumption permits us to interpret differences between an animal without a part and a complete animal as if these differences were due entirely to the absence of the part removed.

The most useful biological version of the conception of separate and independent parts is that of a chain of antecedents and consequents—causes and effects. A leads to B leads to C. Meanwhile L leads to K leads to J, and X leads to Y leads to Z. But $A \rightarrow B \rightarrow C$ is independent of, unaffected by, $L \rightarrow K \rightarrow J$, and each of these, in turn, is independent of $X \rightarrow Y \rightarrow Z$.

The usefulness and simplicity of research based on such a principle are seen with special clarity in simple versions of genetics and equally simple versions of physiology. In simple genetics based on the idea of separate parts and independent causal lines, we talk of gene A as the determiner, let us say, of brown eye color; of a the determiner of blue. In similar fashion we may speak of B as a determiner of height, C of curly hair, and so on, assuming as we speak that no one of these will modify the effect of the other. That is, we speak as if an animal whose genetic composition is $AABBCC$ will have precisely the same eye pigment as one whose composition is $AAbbcc$. As long as A is thought of as *the* gene for brown eye pigment, then whether it is in the company of B or b, C or c, there will be no influence on the effect A has on eye pigment.

In simple physiology, similarly, we have experiments and conclusions based on the assumption of separate causal lines. We speak of organ or tissue A as having effect a; we speak of organ B as having effect b, and so on. Here, as in the case of genetics, there is the underlying basic assumption that organ A will produce effect a whether organ B or C or D is present or absent. Again, each chain of causes and effects, each causal line goes its way independent of other causal lines.

It is this conception of independent causal lines, independent chains of antecedent-consequent connection, that leads to the pattern of enquiry illustrated in our Invitations so far. Let us take a problem in the area of physiology to exemplify the major steps in this pattern. The basic steps are as follows. First, we must identify the members of a set of antecedents. Second, we must identify the mass of consequents made up of the many different consequents flowing sep-

arately from each antecedent. With our identified set of antecedents in hand, together with the mass of consequents, the next task is to perform an experiment which will identify the consequent of each given antecedent. Let us see how this works out in the case of physiology.

Let us take the cat as our case in point. We take all the separate organs identified by anatomical study of the cat as our set of identified antecedents. We then treat the whole physiological condition of the normal cat as made up of the many consequents of all these antecedents. Then our experimental identification or linking up of consequent to antecedent proceeds as follows. In a number of cats we remove *one* particular organ. When the animals have presumably recovered from the effects of the surgery, we scrutinize the physiology of these experimental animals in search of differences from intact animals.

When these differences are noted we then treat them as signs or evidence of the *absence* of that physiological consequent which normally follows from the removed organ when that organ is present. We then try to interpret these signs of absence so as to be able to say what the "presence" is; that is, what the organ does when it is present.

Thus, if we find that removal of the thyroid gland leads to lower temperature, placidity, obesity, lower respiratory rate, reduced consumption of oxygen, and so on, we interpret these as absences, as indicators of something called the "basal metabolism" which is normally maintained by the thyroid gland. This maintenance of basal metabolism is then the discovered consequent of thyroid activity taken as antecedent.

The vast quantity of biological knowledge that takes the form of antecedent-consequent connections bears ample witness to the strength and usefulness of the conception of separate causal lines. It has a central weakness, however, which is, in fact, the basic idea behind the causal line—the idea of its independence from every other line. Biologists know that "causes" or "antecedents" in living organisms may *not* be independent. They do not necessarily act the same way regardless of the company they keep. On the contrary, a living organism is so much an integrated whole that the opposite is almost the rule: Every "cause" is likely to have a different effect, depending on what other causes are operating at the same time.

This massive interaction of causes can arise from either of two different behaviors. On the one hand, if cause A is the cause we are interested in, we may think of cause *B* as affecting cause *A* in a certain way. Then, of course, the effect of cause *A* will differ depending on whether cause *B* is acting or not, since *A* in these two cases will, in effect, be two different causes. On the other hand, cause *B* may have an effect on the same end organ as does cause *A*. In that case, again, the apparent effect of cause A will differ depending on whether cause *B* is acting or not.

Physiology offers us an excellent example of this kind of interaction. If we remove islet tissue of the pancreas from a number of experimental animals, we find that absence of this tissue leads to violent upset in the utilization of sugar and fats. If in another group of experimental animals we removed the pituitary gland (anterior lobe), we find cessation of bone growth and of sexual maturation and function. If we now remove *both* organs from the *same* animals we discover consequences very different from the expectation based on the notion of separate causal lines. Animals with both these tissues removed do not exhibit merely the same failure of sugar and fat metabolism together with the same failure of bone growth and sexual maturation seen in the cases of separate removal. On the contrary, failure of regulation of sugar metabolism is much *less* severe when both organs are removed than it is when the islet tissue alone is removed. In short, the concept of an organism as consisting of separate and independent causal lines is a highly simplified model of the organism.

The fact that the concept is a highly simplified model does not mean, however, that it is one to be discarded. On the contrary, it has given us and will continue to give us a vast quantity of knowledge about the organism. The fact that the model is simpler than the reality means only that we need other models leading to other kinds of experiments, other kinds of data, and, therefore, other kinds of knowledge of the organism.

Specifically, we need a concept which brings back into the picture what the idea of separate causal lines so conspicuously leaves out—the organism as a whole. The idea of separate causal lines says, in effect, that there is no whole in any functional sense. Instead, the concept treats the organism simply as a collection, not an organization, of causes. Each causal line, taken separately, is the object of investigation. The web formed by these lines is not investigated.

The concept of *function* is one of the principles of enquiry that does bring back the organism as a whole. This concept and the simple way it operates are illustrated in the Invitations of Group IV.

INVITATIONS TO ENQUIRY, GROUP III

Quantitative Relations in Biology: Linear Relations, Exponential Relations, Rate, Change of Rate, Units and Constants

LIST OF INVITATIONS (26-31)

Invitation	Subject	Topic
26	Oxygen and carbon dioxide in respiration	Linear relation
27	Light intensity and photosynthesis	Linearity; limiting factors
28	Rate of fermentation	Change of rate; complicated variables
29	Growth regulation in leaf	Nonlinear polynomial of degree >1
30	Light and auxin formation	Nonlinear polynomial of degree <1
31	Population growth in bacteria	Exponential functions; exponent > 1

INVITATIONS TO ENQUIRY, GROUP IV

The Concept of Function: Evidences for Inferring Function, the Doubtfulness of Functional Inferences, Argument from Design versus Argument from Adaptation

LIST OF INVITATIONS (32-37)

Invitation	Subject	Topic
32	Muscle structure and function	Six evidences of function
33	Simple examples of evidence of function	Seven evidences of function
34	Muscle synergism and function	Function in a system
35	Muscle and bone	Function in a system
36	The valves of the veins	Experimental evidence of function
37	Embryonic circulation	Persistence as evidence of function

Interim Summary 4

The Concept of Functional Part

PART AND WHOLE

In Invitations 32 to 37 we have seen the operation of a principle of enquiry which gives special weight to the whole, one which treats parts as subservient to the whole and to be investigated by asking what role they serve in the economy of the whole.

In this conception the "whole" has first place. It is a "going concern" with a certain character or nature. That character or nature is expressed through a number of capacities and activities characteristic of it. Thus the character or nature we call "animal" is expressed through a catalogue of capacities and activities as familiar as it is venerable, that is, ingestion, digestion, distribution and assimilation, excretion, locomotion, integration, reproduction, and so on. The character or nature of a specific animal would be expressed through specific versions of these generic traits plus certain others which set that species apart from other species.

These capacities and activities, in turn, make certain demands. There are conditions that must be held within bounds and needs that must be supplied if they are to be maintained. It is here that the "parts" play their role. They are the servants of the whole, supplying its needs as well as constituting its visible existence.

In this conception the notion of "parts" is very flexible. For the purposes of one stage of investigation, they may be taken to be such gross parts as the entire circulatory system, the digestive tract, the nervous system, and so on. At another stage, we may focus down, treat each system, for the time being, as a "whole," and investigate its parts, the organs. Organs, in turn, may be treated as wholes while we investigate, as their parts, the tissues, the variety of cells, even the microstructures, which compose and maintain them.

The pattern of enquiry which flows from this conception of part and whole is two-pronged. First, there must be some preliminary general knowledge of the whole: a grasp of its character and nature, and a detailing of this character and nature as we have noted. We have already seen examples of this procedure: detailing of animal character in terms of ingestion, digestion, and so on; specification of human character in terms of a modified animal character plus those further behaviors which set men apart from other animals.

This general character of the whole is discovered through the classical process called induction. In this process numerous instances of each kind of thing are scrutinized in their normal state and condition. From this repeated observation of them comes the state of mind called "experience"; from experience, in turn, comes the inductive leap that discards individual variability and the incidental and takes hold of what is central and characteristic.

This process is not a guaranteed one. Our sample of instances may be biased (atypical). The selective observations of different investigators will select in different ways, depending on their past histories and interests. Hence, disagreement as to the essential character of the "kind" under investigation will arise. (This is the principal source of the shades of opinion and the diversities of organization which are found wherever men develop classificatory schemes in which "kinds" are distinguished and defined.) As we shall see, however, the pattern of enquiry used to investigate parts not only requires this prior, inductive investigation of the whole but progressively corrects it.

THE PATTERN OF ENQUIRY: PART RELATIVE TO WHOLE

When we have our preliminary, inductive grasp of the whole reasonably well established, we are ready to turn to investigation of the parts. The leading question we are to ask in each such investigation is clear enough: What is the role of each part in the whole economy? What does it do *for* the whole?

What is not at all clear, however, is what data we need to answer such a question and how these data are to be interpreted. It is at this point that the conception makes its crucial commitment, sets forth the notion which is at once its greatest strength and its sorest point. That notion is briefly and simply this: The *structure* of every part, the *location* of every part, and the observable *actions* of or in every part

are all appropriate to, neatly fitting for, the role it plays in the whole (see also pages 193–194).

This crucial notion brings the functional conception to life, makes it an operative principle of enquiry, by telling us what data to seek and what questions to ask in our laboratory. If the structure, location, and action of each part *is* appropriate to its role, then, from knowledge of structure, location, and action, we should be able to infer that role. These matters, then, are what we should seek to discover as our data: What is the shape, the architecture, the detailed structure of the part we are investigating? Second, we ask, What are its neighbors and how is it connected with them; what does it pass on to them, or do to them? Third, What are its activities? That is, what perceptible motions are there (as in the heart)? What do we see entering them? Leaving them? Happening within them? What chemical changes? Physical changes?

We now also know what to do with these data when we have them. We are to treat them as indicators, evidence of what the part does for the whole. We are to interpret the structure of the part as being what it is because that is the structure which will best (or effectively) enable the part to serve its function. The connections of this part to other parts similiarly exist as the connections which best enable it to play its role. So too, the motions and changes which take place in the part.

One fine example of the use of this principle of enquiry is Harvey's investigation of the role of the heart. First, he examined its structure: the chambers into which it was divided, the movable flaps which guard the entry into each chamber, the arrangement of the fibers which compose its walls. By a closer study he identified these fibers as muscular. He then asked himself what such a structure and arrangement would do. He traced the consequences of contraction of the muscle fibers: They were so arranged that their contraction would result in an overall reduction in the volume of the chambers of the heart. He then took note of the consequences of such a constriction on the blood the heart contained. He saw that, in view of the connections of chambers to one another, and in consequence of the arrangements of the flaps at entry and exit, the blood would be impelled through certain pathways from chamber to chamber and thence out.

Having thus inferred what he could from structure, Harvey turned to the question of connection of the heart with its neighbors, saw the emergence of vessels leading to and from the lungs, and others leading to and from the remainder of the body. By further study of the structure of these vessels (whether their walls were muscular; if so, whether as strong as or weaker than those of the heart; whether they too had valves; and if so, permitting flow in what direction) he sought data that would check his inferences from the structure of the heart and lead to independent inferences which would either be consistent with or opposed to the inferences made from the structure of the heart.

Finally, although there is no significance to the order in which structure, action, and location are examined and interpreted, he turned to the visible actions of heart and blood vessels, noted the order and sequence of contractions and expansions, the alternate paling and reddening of heart wall and blood vessels, and so on. Here he had still a third body of data from which to infer function and with which to check his other inferences.

Thus, he came to the conclusion that the role of the heart is to pump blood in a constant circulation from lungs to heart to body, thence back to the lungs.

This, of course, is not the end of the work, for he had not yet connected this movement of the blood to the whole economy, the need or needs of the body which, ultimately, this circulation serves. This matter remains to be firmly established, but there is already a clue—the clear, great emphasis in the body on flow through the lungs. All the blood passes through the lungs at each complete circuit, whereas only a fraction goes to any other single part (note here the further use of data about connections and neighbors). So, the next problem for enquiry is indicated. What happens to the blood in its passage through the lungs?

If and when that question is answered, we shall note other organs which are more richly supplied with blood vessels than the ordinary and seek to discover what special events take place there. Finally, we shall try to trace the connection between what happens to the blood in lungs and other major places and the needs of the body in general.

KNOWLEDGE OF PART AND WHOLE

When enquiry controlled by the functional principle is well done, a kind of knowledge emerges which is quite different from that brought to being through the principle of causal lines. From the latter come items of knowledge such as the following, each of them from a different research, reported in different scientific papers and recorded in different sections of a textbook:

1. Chemicals produced by some bacteria stimulate and direct the movement of white blood cells.

2. In cases of local infection by many bacteria, the physical state of the neighboring blood vessel walls is altered. In consequence, materials flow out which do not do so ordinarily. For example, fibrinogen, the precursor of fibrin strands, may flow out in considerable quantity.

3. Various bacterial products are known to increase the phagocytic (engulfing) activity of white blood cells.

From enquiry directed by the functional conception, on the other hand, would come something like the following:

When bacteria invade a local area, as by a scratch or puncture wound, a number of processes are set in motion which serve eventually to wall off the infected area, prevent the spread of the invading organisms, and destroy the developing colony of invaders.

The statement would then go on to report the detailed steps by which these ends are achieved. In so doing, it would include all the items which emerged as fruits of causal-line enquiries, but these details would be related to one another and to the whole organism by exhibiting the roles they played in protecting the body against invading bacteria.

Note that the two familiar words "organ" and "function" have their origin in this concept of part and whole. "Organ" means much more than merely a distinguishable part; it means an agent, a subordinate, a something in the service of the whole. "Function" means much more than a mere doing; it means a doing which is seen and understood and phrased in terms of the service it renders to the whole.

It is in this concept of the organism that the central place of anatomy and physiology as sciences of great dignity has its origin. Anatomy is responsible for discovery and description of the structure, topography, and architecture of parts. Physiology is responsible for discovery of motions and actions and for interpretations of all the data on structure, location, action, to a conclusion about function.

STRENGTHS AND WEAKNESSES

There are shortcomings and objections to this classical (going back to Aristotle and Galen) concept of the organism, just as there are weaknesses in the concept of independent causal strands. There are also major advantages. Let us examine some of each.

Its principal virtue consists in the fact that it brings "the organism," the whole, back into the field of enquiry. The whole is lost in the concept of independent causal strands and this loss has consequences for enquiry.

A second and less obvious advantage of the classical conception over that of independent causal lines is this: It permits an integration of many biological sciences, the interconnecting of many different lines of enquiry. We have already seen that it requires an integration of anatomy and physiology, the two being joined to give us the data and the conclusions about functions. It also serves to relate psychology and ecology on the one hand and physics and chemistry on the other to the sciences of anatomy and physiology. It thus brings into existence an organized "whole" of biological knowledge which mirrors the very "whole," the living organism, with which it deals.

Knowledge of the physics and chemistry of living things is joined very simply to our knowledge of their anatomy and physiology. Just as we investigate organs as composing and serving functions in the whole, so we investigate physical components and processes and chemical components and processes as composing and serving functions within the organization of the tissues, cells, and organs which comprise them.

At the other end of the line, ecology and psychology are similarly organized into the structure of biological knowledge. Once we have, for example, studied the nesting, migrating, and nurturing behavior of birds, we can turn back and ask how all these complex behaviors are achieved. What organs serve to initiate the flight northward? What is it that turns the energy of the bird to the building of a nest?

When the involved organs are located, we can ask still further questions which relate the physics and chemistry of the bird's cells, as well as its organs, to its behavior as a bird. How do changes in the proportion of dark to daylight, or seasonal changes in temperature, lead to further chemical and physical changes within the organ which, in turn, lead to still further chemico-physical changes triggering flight, or nesting, or mating, or brooding?

With so much to be said in favor of the classical concept of the organism, it is hard, at first, to see what weaknesses it may have and what objections to it can be raised. But weaknesses there are and objections, indeed violent ones, have been raised.

One of the most serious objections to the concept of function as a principle of enquiry is that it treats organisms as if they were works of fine art. They have finish, completeness. Everything about each organism is as it should be. It could not have been otherwise; it would, presumably, have great difficulty in surviving a transition to something other than it now is.

There are two ways we can take this criticism; one is important to our understanding of it as a principle of enquiry, the other is not. We can take it as a statement of fact: The organism is not finished and perfect; it is not inflexibly what it is. Certainly these critical assertions are true. The organism has had a history of change. There are remnants in its body of past organizations, now pointless and irrelevant, "functionless." Moreover, we know that there are mechanisms built into the living organism by which further change is at least promised if not made inevitable. These changes will often occur piecemeal. Consequently, some organisms, even large populations of them, may possess characteristics (parts) which are merely tolerable in the present working scheme rather than effective, necessary elements of its organization.

Although these assertions are sound, they do not, for this reason, constitute a criticism of the classical concept as a principle of enquiry. Let us grant that many organs of the body are less than perfectly adapted to their roles. Grant further that some organs, whatever their source in past or projected conditions of the organism, are presently without a function. It is still the case that fruitful knowledge will be disclosed by asking the questions and seeking the data prescribed by the principle.

If the part which concerns our research *is* well adapted in structure, action, and location to its role, then our research will disclose that role. If the organ is less than perfect, if it includes remnants of past roles and aspects that presently have no role, our research will have loose ends. Some data collected will find no place in our final formulation of the role played by the part. Moreover, we may need to verify our first conclusions by studying many more neighboring and connected parts than would otherwise be required.

It may even be the case that our interest will have lighted on a structure that has no function, that is not, in the sense of the classical principle, an organ at all. In that case the data we require will not be forthcoming. The thing under investigation will refuse to answer the question we put because, in this case, it has no answer. This very silence, though, is evidence we can use. It points to the possibility that in this case we *are* dealing with a part which does not "belong," and this, too, is proper knowledge of the organism with which we are dealing.

In short, if we admit the desirability of finding answers which are only probable, in which we can have a *degree* of confidence rather than absolute sureness, the classical conception remains a fruitful principle of enquiry despite its limitations.

INVITATIONS TO ENQUIRY, GROUP V

The Self-Regulatory Organism: Homeostasis; Dynamic Equilibriums; Organismic Behavior; Adaptive Change of Equilibriums; Interconnections of Homeostases

LIST OF INVITATIONS (38-44)

Invitation	Subject	Topic
38	A thermostatic model	The concept of homeostasis
39	Control of blood sugar	Maintenance of dynamic equilibrium
40	Blood sugar and the internal environment	Fitness of models
41	Blood sugar and insulin	Sensing mechanisms of homeostasis
42	Blood sugar and hunger	Organismic behavior as homeostatic
43	Basal metabolic rate	Adaptive change of equilibriums
44	The stress reaction: adrenaline	Interrelations of homeostases: the self-regulating organism.

Interim Summary 5

The Whole as Determiner of Its Parts

EXAMPLES OF SELF-REGULATION

When blood sugar drops to an "uncomfortable" level, events are triggered which tend to remedy the situation. One mechanism leads to release of stored sugar by the liver. We are impelled by another to stop what we are doing and seek out food. (There is evidence, indeed, that some animals seek out the particular kind of food they need.) Still a third mechanism stops down the rate at which our muscles consume the sugar that is available.

Conversely, when too much candy has raised the blood sugar level, similar but contrary processes are evoked. The kidney extracts sugar for excretion. The liver stores as much as it can; so do muscles. Hunger pangs cease. Our appetite is "spoiled."

This homeostatic regulation, however, is not the whole story. A more profound change can occur. The body can *"reset its thermostat."* If whim or circumstance puts us on short rations for a time, the thermostat behaves, at first, as it did before. It irks us by way of hunger pangs and lassitude and calls for stored sugar from the liver. If we stay on the short rations long enough, however, the impulsion called hunger ceases; the muscles readjust the ways in which they take energy from available materials; the liver releases its store only when blood sugar drops to a level measurably lower than the level which formerly evoked release. And this new state of affairs persists even if we return to a "fuller life"—until we have stayed on it for awhile.

Enquiry has disclosed many instances of this kind of reset of a thermostat or second-order control which legislates a new "normality." When a muscle is called into activity, many capillary beds open which normally are closed. When exercise ceases, the beds close down again. If the muscle is used repeatedly over a sufficient length of time, however, the number of beds which supply it, even in its resting state, is generally increased, and an exercise call for extra supply is answered by a proportionate increase.

A similar shift of norm occurs for the basal rate at which our body releases energy for maintenance. It rises if we stay long enough in a cooler climate and drops if we spend sufficient time in a warmer one. It occurs, too, in the case of water utilization by the kidneys and, again, in the case of body temperature. In brief, the body can shift its norms as well as correct departures from them.

These instances seem commonplace. In the first place, they are only second-order instances of a host of ephemeral adjustments to need and circumstances which are of the essence of being alive. In the second place, they are changes in rate, in degree, which we tend to take for granted. But let us look further.

At first glance, mountain sickness appears to be but another instance of second-order change in degree. When we move to a high altitude, distress—shortness of breath, fatigue, nausea, and so on—usually ensues. The amount of oxygen in the volume of air we breathe is so much less than that at sea level that our demand, even under the quietest circumstances, exceeds the available supply. In two weeks or three or four, however, this is changed. The thin air of the heights is now adequate: We extract from it as much oxygen as we require.

Many of the changes which bring about this more satisfactory state of things are only changes in degree: increase in the amount of oxygen-carrying pigment in the blood, increased blood pressure and circulatory rate. But at least one extensive study provides evidence of change of a different kind, a change in the very architecture and chemistry of an organ.

The organ is the lung. Under sea-level conditions its cells are only epithelial: They constitute a membrane. The oxygen of inspired air and the carbon dioxide brought by the blood are thought to move across it by ubiquitous physical means: solution in water, then diffusion from regions of higher to regions of lower concentration. The inspired air has a higher oxygen "tension" than has the blood which flows through the membranes of the lung spaces; the blood has much more carbon dioxide than does the inspired air. In consequence, exchange occurs simply as a result of the relative frequencies of molecular collisions.

After adjustment to high altitude, all this is changed—if we accept

the research of J. S. Haldane. He undertook measurement of oxygen tension—in the ambient air, in the lung spaces, in the blood flowing to and away from the lungs—among members of an expedition to Pikes Peak. When members of the expedition reached adjustment to altitude—no longer showed symptoms of mountain sickness—Haldane's data showed oxygen tensions *lower* in the alveolar air of their lungs than in the passing blood. In short, oxygen was moving *against* the concentration gradient. The indicated conclusion was that under the condition of oxygen want, sufficiently long maintained, the very structure and action of lung membrane was transformed. It was no longer an epithelium across which oxygen "moved itself" but a secretory organ which moved oxygen "forcibly," by the expenditure of energy (active transport).

Though Haldane's data have been challenged (because of the doubtful accuracy of the assays of alveolar air) his conclusion remains a tenable possibility.

There are similar cases which have not been challenged. There is compensatory over-growth of one kidney if the other is damaged or removed. Similar compensation occurs in testes. There are well-documented instances of increase in auditory acuity after loss of vision. (In this case it is not clear, however, whether we are dealing with the structural change of ear or nerve, or with "learning.")

Karl Lashley reports similar flexibility in local functioning of the brain. Animals are taught a certain behavior. Then, by trial, the brain area which is the locus of this learning is located and destroyed. When the animals recover from the microsurgery they are retrained on the same problem. They learn it—in another area of the brain.

Now, three more cases—from experimental embryology.

1. Before the outgrowth of nerves, the forelimbs of amphibian embryos are transplanted to a site forward or to the rear of their normal position. Development proceeds. Each transplanted limb receives a full complement of nerves from the spinal cord. But they are *not the nerves they would ordinarily have received.* Instead, they are nerves from a different segment of the spinal cord, nerves which would, in "normal" circumstances, have gone elsewhere to perform another service.

2. Remove one developing eye from an amphibian; transplant it to another, in line with one of its eyes and immediately adjacent to it. The two rudiments grow, make contact, and *reassort their constituent cells.* From the two rudiments come not two eyes, but one, its parts in harmonious relation with one another.

3. The middle kidney is removed from a chick embryo. By treatment with alkali and a material which digests protein it is disintegrated into a mere suspension of separated cells. The suspension of separated cells is then placed in a culture medium. The cells grow, multiply, migrate, cling to one another, and in three days or thereabouts the culture dish contains identifiable units of a kidney. "The discrete cells," say the authors of this work, "are thus capable of re-establishing the structural pattern of their tissue of origin." (A. and H. Moscona, *J. Anat.*, **86**, 1952, 287–301.) Says another scientist of a similar capability in the cells of an *Amblystoma* embryo: There was directed cell migration, selective cellular adhesions, mutual assimilative inductions. (Johannes Holtfreter, from "Growth in Relation to Differentiation and Morphogenesis," *Symposia Soc. Exptl Biol.*, No. 2, 1948.)

Here, then, are a number of instances of the flexibility of the organism. There is not one concentration of sugar which is "right" for the organism but several, depending on the condition and activity of many (or all?) other chemicals, physical factors, and structures of the body. There may be not one anatomy of the lung, but two—perhaps three or more—depending, again, on the condition of the company it keeps, the state of other organs, the condition of the outward world with which the organism interacts. There is not one normal size for a kidney, not even a normal average, but several sizes, depending on the demand its brother parts make. The same holds for the blood supply to muscles, the size of muscles, even the size of that principal muscle, the heart. The organization of the brain is flexible, its parts multivalent, pluripotent. When a part is lost or damaged, its role may be taken over by another part.

In the embryo, the "normal" fate of a given cell or group of cells is subject to change. Instead of becoming what it usually becomes, it conforms to the organization in which it may be put by change of circumstance—even radically altered circumstance—and plays the part that fits that organization. Paul Weiss says, with moving imagery, ". . . newt belly skin grafted to an axolotl head has . . . complied with the locality (of the host) but has done so in a manner characteristic of the donor. . . . The cells have reacted to the lateral head field of the *axolotl* to the best of their *newt* knowledge." (*Principles of Development*, Henry Holt, New York, 1939.)

Such events as these point to the usefulness of a principle of enquiry in biology, one that will open doors to which the classical conception has no key. The classical conception in its pristine form depends on a fixed structure, a fixed function, and a fixed relation between the two. A fixed function is the knowledge object at which the enquiry aims. A definite structure (and action) is required in order to yield the data which this pattern of enquiry must use. A fixed relation between the two is the ground on which the data of structure, locus, and action are interpreted to yield knowledge of function.

By contrast, such flexibilities and varipotencies as we have just described point to a new knowledge-object which requires a new kind of data and a new pattern for its interpretation. Instead of knowledge about *one* collection of regular, recurrent parts, we will want knowledge about changeable parts within the set; even, possibly, of changeable sets. For example, we would no longer ask, "What is *the* cellular structure of the lung?" Rather, we would ask (by analogy to Haldane's report), "What is the *repertory* possessed by this organ, the *several* cellular arrangements and architectures of which it is capable?"

This new question would bring in its wake two related ones: (1) What conditions evoke this, that, or the other item in the repertory? (2) What are the complex, subtle processes by which one item of the repertory, one cellular architecture, is replaced by another?

By questions such as these we could seek out the flexibilities of our "parts." We also want to seek out the flexibilities of our "whole." This can be done by an analogous shift of the problem we pose. We would no longer ask, "What is the function or role of this organ?" Instead, we would ask, "When parts *X*, *Y*, and *Z* do thus and so, what role does part *A* play?" We would then ask, "When *X*, *Y*, or *Z* is changed in such-and-such a way, what correlative change takes place in *A*—what new roles does it play to make of *A*, *X*, *Y*, and *Z* an integrated whole?"

Such a pattern of research reflects the conception of the self-regulatory organism.

APPENDIX B

COPY OF "EXPERIMENTS IN PLANT HYBRIDISATION" (pp. 1-13), BY GREGOR MENDEL

This paper was used in Shawnee Mission West high school biology classes as a basis for "Inquiry into Inquiry" discussion in Chapter Seven. It is reprinted from "Experiments in Plant Hybridisation" by Gregor Mendel, Harvard University Press, Cambridge, 1958, with permission of the publisher.

EXPERIMENTS IN PLANT-HYBRIDISATION[1]

By Gregor Mendel

(Read at the Meetings of the 8th February and 8th March, 1865.)

INTRODUCTORY REMARKS

Experience of artificial fertilisation, such as is effected with ornamental plants in order to obtain new variations in colour, has led to the experiments which will here be discussed. The striking regularity with which the same hybrid forms always reappeared whenever fertilisation took place between the same species induced further experiments to be undertaken, the object of which was to follow up the developments of the hybrids in their progeny.

To this object numerous careful observers, such as Kölreuter, Gärtner, Herbert, Lecoq, Wichura and others, have devoted a part of their lives with inexhaustible perseverance. Gärtner especially, in his work "Die Bastarderzeugung im Pflanzenreiche" (The Production of Hybrids in the Vegetable Kingdom), has recorded very valuable observations; and quite recently Wichura published the results of some profound investigations into the hybrids of the Willow. That, so far, no generally applicable law governing the formation and development of hybrids has been successfully formulated can hardly be wondered at by anyone who is acquainted with the extent of the task, and can appreciate the difficulties with which experiments of this class have to contend. A final decision can only be arrived at when we shall have before us the results of detailed experiments made on plants belonging to the most diverse orders.

Those who survey the work done in this department will arrive at the conviction that among all the numerous experiments made, not one has been carried out to such an extent and in such a way as to make it possible to determine the number of different forms under which the offspring of hybrids appear, or to arrange these forms with certainty according to their separate generations, or definitely to ascertain their statistical relations.[1]

It requires indeed some courage to undertake a labour of such far-reaching extent; this appears, however, to be the only right way by which we can finally reach the solution of a question the importance of which cannot be overestimated in connection with the history of the evolution of organic forms.

The paper now presented records the results of such a detailed experiment. This experiment was practically confined to a small plant group, and is now, after eight years' pursuit, concluded in all essentials. Whether the plan upon which the separate experiments were conducted and carried out was the best suited to attain the desired end is left to the friendly decision of the reader.

Selection of the Experimental Plants

The value and utility of any experiment are determined by the fitness of the material to the purpose for which it is used, and thus in the case before us it cannot be immaterial what plants are subjected to experiment and in what manner such experiments are conducted.

The selection of the plant group which shall serve for experiments of this kind must be made with all possible care if it be desired to avoid from the outset every risk of questionable results.

The experimental plants must necessarily —

1. Possess constant differentiating characters.
2. The hybrids of such plants must, during the flowering period, be protected from the influence of all foreign pollen, or be easily capable of such protection.

The hybrids and their offspring should suffer no marked disturbance in their fertility in the successive generations.

Accidental impregnation by foreign pollen, if it occurred during the experiments and were not recognized, would lead to entirely erroneous conclusions. Reduced fertility or entire sterility of certain forms, such as occurs in the offspring of many hybrids, would render the experiments very difficult or entirely frustrate them. In

[1] This translation was made by the Royal Horticultural Society of London, and is reprinted, by permission of the Council of the Society, with footnotes added and minor changes suggested by Professor W. Bateson, enclosed within [ ]. The original paper was published in the *Verh. naturf. Ver. in Brunn, Abhandlungen*, iv. 1865, which appeared in 1866.

[1] [It is to the clear conception of these three primary necessities that the whole success of Mendel's work is due. So far as I know this conception was absolutely new in his day.]

order to discover the relations in which the hybrid forms stand towards each other and also towards their progenitors it appears to be necessary that all members of the series developed in each successive generation should be, *without exception*, subjected to observation.

At the very outset special attention was devoted to the *Leguminosae* on account of their peculiar floral structure. Experiments which were made with several members of this family led to the result that the genus *Pisum* was found to possess the necessary qualifications.

Some thoroughly distinct forms of this genus possess characters which are constant, and easily and certainly recognizable, and when their hybrids are mutually crossed they yield perfectly fertile progeny. Furthermore, a disturbance through foreign pollen cannot easily occur, since the fertilising organs are closely packed inside the keel and the anther bursts within the bud, so that the stigma becomes covered with pollen even before the flower opens. This circumstance is of especial importance. As additional advantages worth mentioning, there may be cited the easy culture of these plants in the open ground and in pots, and also their relatively short period of growth. Artificial fertilisation is certainly a somewhat elaborate process, but nearly always succeeds. For this purpose the bud is opened before it is perfectly developed, the keel is removed, and each stamen carefully extracted by means of forceps, after which the stigma can at once be dusted over with the foreign pollen.

In all, thirty-four more or less distinct varieties of Peas were obtained from several seedsmen and subjected to a two years' trial. In the case of one variety there were noticed, among a larger number of plants all alike, a few forms which were markedly different. These, however, did not vary in the following year, and agreed entirely with another variety obtained from the same seedsman; the seeds were therefore doubtless merely accidentally mixed. All the other varieties yielded perfectly constant and similar offspring; at any rate, no essential difference was observed during two trial years. For fertilisation twenty-two of these were selected and cultivated during the whole period of the experiments. They remained constant without any exception.

Their systematic classification is difficult and uncertain. If we adopt the strictest definition of a species, according to which only

those individuals belong to a species which under precisely the same circumstances display precisely similar characters, no two of these varieties could be referred to one species. According to the opinion of experts, however, the majority belong to the species *Pisum sativum;* while the rest are regarded and classed, some as sub-species of *P. sativum*, and some as independent species, such as *P. quadratum*, *P. saccharatum*, and *P. umbellatum*. The positions, however, which may be assigned to them in a classificatory system are quite immaterial for the purposes of the experiments in question. It has so far been found to be just as impossible to draw a sharp line between the hybrids of species and varieties as between species and varieties themselves.

Division and Arrangement of the Experiments

If two plants which differ constantly in one or several characters be crossed, numerous experiments have demonstrated that the common characters are transmitted unchanged to the hybrids and their progeny; but each pair of differentiating characters, on the other hand, unite in the hybrid to form a new character, which in the progeny of the hybrid is usually variable. The object of the experiment was to observe these variations in the case of each pair of differentiating characters, and to deduce the law according to which they appear in the successive generations. The experiment resolves itself therefore into just as many separate experiments as there are constantly differentiating characters presented in the experimental plants.

The various forms of Peas selected for crossing showed differences in the length and colour of the stem; in the size and form of the leaves; in the position, colour, and size of the flowers; in the length of the flower stalk; in the colour, form, and size of the pods; in the form and size of the seeds; and in the colour of the seed-coats and of the albumen [cotyledons]. Some of the characters noted do not permit of a sharp and certain separation, since the difference is of a "more or less" nature, which is often difficult to define. Such characters could not be utilised for the separate experiments; these could only be applied to characters which stand out clearly and definitely in the plants. Lastly, the result must show whether they, in their entirety, observe a regular behaviour in their hybrid unions, and whether from these facts any conclusion can be come to regarding those characters which possess a subordinate significance in the type.

The characters which were selected for experiment relate:

1. To the *difference in the form of the ripe seeds*. These are either round or roundish, the depressions, if any, occur on the surface, being always only shallow; or they are irregularly angular and deeply wrinkled (*P. quadratum*).

2. To the *difference in the colour of the seed albumen* (endosperm).[1] The albumen of the ripe seeds is either pale yellow, bright yellow and orange coloured, or it possesses a more or less intense green tint. This difference of colour is easily seen in the seeds as [= if] their coats are transparent.

3. To the *difference in the colour of the seed-coat*. This is either white, with which character white flowers are constantly correlated; or it is grey, grey-brown, leather-brown, with or without violet spotting, in which case the colour of the standards is violet, that of the wings purple, and the stem in the axils of the leaves is of a reddish tint. The grey seed-coats become dark brown in boiling water.

4. To the *difference in the form of the ripe pods*. These are either simply inflated, not contracted in places; or they are deeply constricted between the seeds and more or less wrinkled (*P. saccharatum*).

5. To the *difference in the colour of the unripe pods*. They are either light to dark green, or vividly yellow, in which colouring the stalks, leaf-veins, and calyx participate.[2]

6. To the *difference in the position of the flowers*. They are either axial, that is, distributed along the main stem; or they are terminal, that is, bunched at the top of the stem and arranged almost in a false umbel; in this case the upper part of the stem is more or less widened in section (*P. umbellatum*).[3]

7. To the *difference in the length of the stem*. The length of the stem[4] is very various in some forms; it is, however, a constant

[Mendel uses the terms "albumen" and "endosperm" somewhat loosely to denote the cotyledons, containing food-material, within the seed.]

[2] One species possesses a beautifully brownish-red coloured pod, which when ripening turns to violet and blue. Trials with this character were only begun last year. [Of these further experiments it seems no account was published. Correns has since worked with such a variety.]

[3] [This is often called the Mummy Pea. It shows slight fasciation. The form I know has white standard and salmon-red wings.]

[4] [In my account of these experiments (*R.H.S. Journal*, vol. xxv. p. 54) I misunderstood this paragraph and took "axis" to mean the *floral* axis, instead of the

character for each, in so far that healthy plants, grown in the same soil, are only subject to unimportant variations in this character.

In experiments with this character, in order to be able to discriminate with certainty, the long axis of 6 to 7 ft. was always crossed with the short one of ¾ ft. to 1½ ft.

Each two of the differentiating characters enumerated above were united by cross-fertilisation. There were made for the

1st	trial	60	fertilisations	on	15	plants.
2nd	"	58	"	"	10	"
3rd	"	35	"	"	10	"
4th	"	40	"	"	10	"
5th	"	23	"	"	5	"
6th	"	34	"	"	10	"
7th	"	37	"	"	10	"

From a larger number of plants of the same variety only the most vigorous were chosen for fertilisation. Weakly plants always afford uncertain results, because even in the first generation of hybrids, and still more so in the subsequent ones, many of the offspring either entirely fail to flower or only form a few and inferior seeds.

Furthermore, in all the experiments reciprocal crossings were effected in such a way that each of the two varieties which in one set of fertilisation served as seed-bearer in the other set was used as the pollen plant.

The plants were grown in garden beds, a few also in pots, and were maintained in their naturally upright position by means of sticks, branches of trees, and strings stretched between. For each experiment a number of pot plants were placed during the blooming period in a greenhouse, to serve as control plants for the main experiment in the open as regards possible disturbance by insects. Among the insects[1] which visit Peas, the beetle *Bruchus pisi* might be detrimental to the experiments should it appear in numbers. The female of this species is known to lay the eggs in the flower, and in so doing opens the keel; upon the tarsi of one specimen, which was caught in a flower, some pollen grains could clearly be seen under a lens. Mention must also be made of a circumstance

main axis of the plant. The unit of measurement, being indicated in the original by a dash ('), I carelessly took to have been an *inch*, but the translation here given is evidently correct.]

[1] [It is somewhat surprising that no mention is made of Thrips, which swarm in Pea flowers. I had come to the conclusion that this is a real source of error and I see Laxton held the same opinion.]

which possibly might lead to the introduction of foreign pollen. It occurs, for instance, in some rare cases that certain parts of an otherwise quite normally developed flower wither, resulting in a partial exposure of the fertilising organs. A defective development of the keel has also been observed, owing to which the stigma and anthers remained partially uncovered.[1] It also sometimes happens that the pollen does not reach full perfection. In this event there occurs a gradual lengthening of the pistil during the blooming period, until the stigmatic tip protrudes at the point of the keel. This remarkable appearance has also been observed in hybrids of *Phaseolus* and *Lathyrus*.

The risk of false impregnation by foreign pollen is, however, a very slight one with *Pisum*, and is quite incapable of disturbing the general result. Among more than 10,000 plants which were carefully examined there were only a very few cases where an indubitable false impregnation had occurred. Since in the greenhouse such a case was never remarked, it may well be supposed that *Bruchus pisi*, and possibly also the described abnormalities in the floral structure, were to blame.

[F_1] The Forms of the Hybrids [2]

Experiments which in previous years were made with ornamental plants have already afforded evidence that the hybrids, as a rule, are not exactly intermediate between the parental species. With some of the more striking characters, those, for instance, which relate to the form and size of the leaves, the pubescence of the several parts, &c., the intermediate, indeed, is nearly always to be seen; in other cases, however, one of the two parental characters is so preponderant that it is difficult, or quite impossible, to detect the other in the hybrid.

This is precisely the case with the Pea hybrids. In the case of each of the seven crosses the hybrid-character resembles [3] that of one of the parental forms so closely that the other either escapes

[1] [This also happens in Sweet Peas.]

[2] [Mendel throughout speaks of his cross-bred Peas as "hybrids," a term which many restrict to the offspring of two distinct *species*. He, as he explains, held this to be only a question of degree.]

[3] [Note that Mendel, with true penetration, avoids speaking of the hybrid-character as "transmitted" by either parent, thus escaping the error pervading the older views of heredity.]

observation completely or cannot be detected with certainty. This circumstance is of great importance in the determination and classification of the forms under which the offspring of the hybrids appear. Henceforth in this paper those characters which are transmitted entire, or almost unchanged in the hybridisation, and therefore in themselves constitute the characters of the hybrid, are termed the *dominant*, and those which become latent in the process *recessive*. The expression "recessive" has been chosen because the characters thereby designated withdraw or entirely disappear in the hybrids, but nevertheless reappear unchanged in their progeny, as will be demonstrated later on.

It was furthermore shown by the whole of the experiments that it is perfectly immaterial whether the dominant character belongs to the seed-bearer or to the pollen-parent; the form of the hybrid remains identical in both cases. This interesting fact was also emphasised by Gärtner, with the remark that even the most practised expert is not in a position to determine in a hybrid which of the two parental species was the seed or the pollen plant.[1]

Of the differentiating characters which were used in the experiments the following are dominant:

1. The round or roundish form of the seed with or without shallow depressions.
2. The yellow colouring of the seed albumen [cotyledons].
3. The grey, grey-brown, or leather-brown colour of the seed-coat, in association with violet-red blossoms and reddish spots in the leaf axils.
4. The simply inflated form of the pod.
5. The green colouring of the unripe pod in association with the same colour in the stems, the leaf-veins and the calyx.
6. The distribution of the flowers along the stem.
7. The greater length of stem.

With regard to this last character it must be stated that the longer of the two parental stems is usually exceeded by the hybrid, a fact which is possibly only attributable to the greater luxuriance which appears in all parts of plants when stems of very different length are crossed. Thus, for instance, in repeated experiments, stems of 1 ft. and 6 ft. in length yielded without exception hybrids which varied in length between 6 ft. and 7½ ft.

[1] [Gärtner, p. 223.]

The hybrid seeds in the experiments with seed-coat are often more spotted, and the spots sometimes coalesce into small bluish-violet patches. The spotting also frequently appears even when it is absent as a parental character.[1]

The hybrid forms of the seed-shape and of the albumen [colour] are developed immediately after the artificial fertilisation by the mere influence of the foreign pollen. They can, therefore, be observed even in the first year of experiment, whilst all the other characters naturally only appear in the following year in such plants as have been raised from the crossed seed.

[F_2] THE GENERATION [BRED] FROM THE HYBRIDS

In this generation there reappear, together with the dominant characters, also the recessive ones with their peculiarities fully developed, and this occurs in the definitely expressed average proportion of three to one, so that among each four plants of this generation three display the dominant character and one the recessive. This relates without exception to all the characters which were investigated in the experiments. The angular wrinkled form of the seed, the green colour of the albumen, the white colour of the seed-coats and the flowers, the constrictions of the pods, the yellow colour of the unripe pod, of the stalk, of the calyx, and of the leaf venation, the umbel-like form of the inflorescence, and the dwarfed stem, all reappear in the numerical proportion given, without any essential alteration. *Transitional forms were not observed in any experiment.*

Since the hybrids resulting from reciprocal crosses are formed alike and present no appreciable difference in their subsequent development, consequently the results [of the reciprocal crosses] can be reckoned together in each experiment. The relative numbers which were obtained for each pair of differentiating characters are as follows:

Expt. 1. Form of seed. — From 253 hybrids 7,324 seeds were obtained in the second trial year. Among them were 5,474 round or roundish ones and 1,850 angular wrinkled ones. Therefrom the ratio 2.96 to 1 is deduced.

Expt. 2. Colour of albumen. — 258 plants yielded 8,023 seeds, 6,022 yellow, and 2,001 green; their ratio, therefore, is as 3.01 to 1.

[1] [This refers to the coats of the seeds borne by F_1 plants.]

In these two experiments each pod yielded usually both kinds of seeds. In well-developed pods which contained on the average six to nine seeds, it often happened that all the seeds were round (Expt. 1) or all yellow (Expt. 2); on the other hand there were never observed more than five wrinkled or five green ones in one pod. It appears to make no difference whether the pods are developed early or later in the hybrid or whether they spring from the main axis or from a lateral one. In some few plants only a few seeds developed in the first formed pods, and these possessed exclusively one of the two characters, but in the subsequently developed pods the normal proportions were maintained nevertheless.

As in separate pods, so did the distribution of the characters vary in separate plants. By way of illustration the first ten individuals from both series of experiments may serve.

	EXPERIMENT 1. Form of Seed.		EXPERIMENT 2. Color of Albumen.	
Plants	Round	Angular	Yellow	Green
1	45	12	25	11
2	27	8	32	7
3	24	7	14	5
4	19	10	70	27
5	32	11	24	13
6	26	6	20	6
7	88	24	32	13
8	22	10	44	9
9	28	6	50	14
10	25	7	44	18

As extremes in the distribution of the two seed characters in one plant, there were observed in Expt. 1 an instance of 43 round and only 2 angular, and another of 14 round and 15 angular seeds. In Expt. 2 there was a case of 32 yellow and only 1 green seed, but also one of 20 yellow and 19 green.

These two experiments are important for the determination of the average ratios, because with a smaller number of experimental plants they show that very considerable fluctuations may occur. In counting the seeds, also, especially in Expt. 2, some care is requisite, since in some of the seeds of many plants the green colour of the albumen is less developed, and at first may be easily overlooked. The cause of this partial disappearance of the green colouring has no connection with the hybrid-character of the plants, as it likewise occurs in the parental variety. This peculiarity

[bleaching] is also confined to the individual and is not inherited by the offspring. In luxuriant plants this appearance was frequently noted. Seeds which are damaged by insects during their development often vary in colour and form, but, with a little practice in sorting, errors are easily avoided. It is almost superfluous to mention that the pods must remain on the plants until they are thoroughly ripened and have become dried, since it is only then that the shape and colour of the seed are fully developed.

Expt. 3. Colour of the seed-coats. — Among 929 plants 705 bore violet-red flowers and grey-brown seed-coats; 224 had white flowers and white seed-coats, giving the proportion 3.15 to 1.

Expt. 4. Form of pods. — Of 1,181 plants 882 had them simply inflated, and in 299 they were constricted. Resulting ratio, 2.95 to 1.

Expt. 5. Colour of the unripe pods. — The number of trial plants was 580, of which 428 had green pods and 152 yellow ones. Consequently these stand in the ratio 2.82 to 1.

Expt. 6. Position of flowers. — Among 858 cases 651 had inflorescences axial and 207 terminal. Ratio, 3.14 to 1.

Expt. 7. Length of st—. — Out of 1,064 plants, in 787 cases the stem was long, and in 277 short. Hence a mutual ratio of 2.84 to 1. In this experiment the dwarfed plants were carefully lifted and transferred to a special bed. This precaution was necessary, as otherwise they would have perished through being overgrown by their tall relatives. Even in their quite young state they can be easily picked out by their compact growth and thick dark-green foliage.[1]

If now the results of the whole of the experiments be brought together, there is found, as between the number of forms with the dominant and recessive characters, an average ratio of 2.98 to 1, or 3 to 1.

The dominant character can have here a *double signification* — viz. that of a parental character, or a hybrid-character.[2] In which of the two significations it appears in each separate case can only be determined by the following generation. As a parental character it must pass over unchanged to the whole of the offspring; as a hybrid-character, on the other hand, it must maintain the same behaviour as in the first generation [F_2].

[1] [This is true also of the dwarf or "Cupid" Sweet Peas.]

[2] [This paragraph presents the view of the hybrid-character as something incidental to the hybrid, and not "transmitted" to it — a true and fundamental conception here expressed probably for the first time.]

[F_3] The Second Generation [bred] from the Hybrids

Those forms which in the first generation [F_2] exhibit the recessive character do not further vary in the second generation [F_3] as regards this character; they remain constant in their offspring.

It is otherwise with those which possess the dominant character in the first generation [bred from the hybrids]. Of these *two*-thirds yield offspring which display the dominant and recessive characters in the proportion of 3 to 1, and thereby show exactly the same ratio as the hybrid forms, while only *one*-third remains with the dominant character constant.

The separate experiments yielded the following results:

Expt. 1. Among 565 plants which were raised from round seeds of the first generation, 193 yielded round seeds only, and remained therefore constant in this character; 372, however, gave both round and wrinkled seeds, in the proportion of 3 to 1. The number of the hybrids, therefore, as compared with the constants is 1.93 to 1.

Expt. 2. Of 519 plants which were raised from seeds whose albumen was of yellow colour in the first generation, 166 yielded exclusively yellow, while 353 yielded yellow and green seeds in the proportion of 3 to 1. There resulted, therefore, a division into hybrid and constant forms in the proportion of 2.13 to 1.

For each separate trial in the following experiments 100 plants were selected which displayed the dominant character in the first generation, and in order to ascertain the significance of this, ten seeds of each were cultivated.

Expt. 3. The offspring of 36 plants yielded exclusively grey-brown seed-coats, while of the offspring of 64 plants some had grey-brown and some had white.

Expt. 4. The offspring of 29 plants had only simply inflated pods; of the offspring of 71, on the other hand, some had inflated and some constricted.

Expt. 5. The offspring of 40 plants had only green pods; of the offspring of 60 plants some had green, some yellow ones.

Expt. 6. The offspring of 33 plants had only axial flowers; of the offspring of 67, on the other hand, some had axial and some terminal flowers.

Expt. 7. The offspring of 28 plants inherited the long axis, and those of 72 plants some the long and some the short axis.

In each of these experiments a certain number of the plants came constant with the dominant character. For the determination of the proportion in which the separation of the forms with the constantly persistent character results, the two first experiments are of especial importance, since in these a larger number of plants can be compared. The ratios 1.93 to 1 and 2.13 to 1 gave together almost exactly the average ratio of 2 to 1. The sixth experiment gave a quite concordant result; in the others the ratio varies more or less, as was only to be expected in view of the smaller number of 100 trial plants. Experiment 5, which shows the greatest departure, was repeated, and then, in lieu of the ratio of 60 and 40, that of 65 and 35 resulted. *The average ratio of 2 to 1 appears, therefore, as fixed with certainty.* It is therefore demonstrated that, of those forms which possess the dominant character in the first generation, two-thirds have the hybrid-character, while one-third remains constant with the dominant character.

The ratio of 3 to 1, in accordance with which the distribution of the dominant and recessive characters results in the first generation, resolves itself therefore in all experiments into the ratio of 2:1:1 if the dominant character be differentiated according to its significance as a hybrid-character or as a parental one. Since the members of the first generation [F_2] spring directly from the seed of the hybrids [F_1], *it is now clear that the hybrids form seeds having one or other of the two differentiating characters, and of these one-half develop again the hybrid form, while the other half yield plants which remain constant and receive the dominant or the recessive characters [respectively] in equal numbers.*

BIBLIOGRAPHY ON BEHAVIORAL OBJECTIVES AND INQUIRY TEACHING IN BIOLOGY

Contents

SECTION I

BEHAVIORAL OBJECTIVES — SOME CONSIDERATIONS

1. Ammerman, H. L. The derivation, analysis and classification of instructional objectives. Human Resources Research Office, George Washington University, Alexandria, Va. Technical Report 66-4. May, 1966. ED 014 793, AD 633 474.

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6. Burns, R. W. The theory of expressing objectives. *Educational Technology,* October 30, 1967, 7 (20).

7. Canfield, A. A. A rationale for performance objectives. *Audiovisual Instruction,* February, 1968, 13 (2), 127-129.

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Seven categories are listed: *(a)* general rationales, *(b)* systems analysis, *(c)* job analysis, *(d)* allocation of training, *(e)* task description, *(f)* determination of knowledges and skills, and *(g)* description of objectives.

37. Smith, R. G., Jr. The development of training objectives. Human Resources Research Office, George Washington University, Alexandria, Va., Research Bulletin 11, 1964.

38. Taylor, P. A., and Maguire, T. O. Perceptions of some objectives for a science curriculum. *Science Education,* December, 1967, 51 (5), 488-493.

This study shows that subject-matter experts, teachers, and curriculum writers have congruent perceptions of science objectives.

39. Tyler, R. W. Some persistent questions on the defining of objectives. In Lindvall, C. M. (Ed.), *Defining educational objectives.* Pittsburgh: University of Pittsburgh Press, 1964.

SECTION II

THE INQUIRY PROCESS

40. Bruner, J. S., Goodnow, J. J., and Austin, G. A. *A study of thinking.* New York: Wiley, 1956.

41. Bruner, J. S. *The process of education.* New York: Random House, 1960.

    Bruner emphasizes the need for connection or structure in knowledge if it is to be meaningful and/or retained.

42. Bruner, J. S. The act of discovery. *Harvard Educational Review,* Winter, 1961, 31 (1), 21-32.

43. Davis, G. A. The current status of research and theory in human problem solving. University of Wisconsin, Madison, Wis., 1966. ED 101 506.

    Summarizes problem-solving theories in three areas: traditional (stimulus-response) learning, cognitive-gestalt approaches, and computer and mathematical models.

44. Educational Policies Commission. *Education and the spirit of science.* Washington, D. C.: National Education Association, 1966. ED 011 507.

    The Educational Policies Commission recommends that schools should be promoting understanding of the values on which science is everywhere based; namely, *(a)* longing to know and understand, *(b)* questioning of all things, *(c)* searching for data and their meaning, *(d)* demanding verification, *(e)* respecting logic, *(f)* considering premises, and *(g)* considering sequences.

45. Educational Services, Inc. *The report of the Cambridge Conference.* Boston: Houghton-Mifflin, 1963.

46. Fox, F. W. Education and the spirit of science – the new challenge. *The Science Teacher,* November, 1966, 33 (8), 58-59.

    The author reviews the recommendations of the Educational Policies Commission.

47. Gagne, R. M. The acquisition of knowledge. *Psychological Review,* 1962, 69 (4), 355-365.

48. Gagne, R. M. Psychological issues in *Science – A process approach.* A lecture delivered at Chicago and San Francisco, 1965.

49. Gagne, R. M. *The conditions of learning.* New York: Holt, Rinehart & Winston, 1967.

    Eight varieties of learning are identified and an account given of the conditions that govern their occurrence.

50. Gagne, R. M. Why the "process" approach for a modern curriculum? *EPIE Forum,* April-May, 1968, 1 (8-9), 11.

    This article presents the rationale of the Commission on Science Education, American Association for the advancement of Science, for their choice of the process approach as the basis of their new elementary science curriculum.

51. Glaser, R. The design of instruction. Learning Research and Development Center, University of Pittsburgh, Pittsburgh, Pa., 1966. Reprint No. 5. ED 011 509.

    The theory and the research relevant to instructional design are discussed in this paper, a chapter from the 65th yearbook of the National Society for the study of education, Part II. Generalization, concept formation, and "process" objectives are discussed in a section devoted to the analysis of subject-matter objectives of instruction.

52. Guilford, J. P. *The nature of human intelligence.* New York: McGraw-Hill, 1967.

53. Hawkins, D. Education and the spirit of science. *The Science Teacher,* September, 1966, 33 (6), 18-20.

While welcoming the recommendations of the Educational Policies Commission in spirit, Dr. Hawkins finds it lacking in body. Its shortcoming lies in labeling virtues as values and then failing to include a statement of values. Dr. Hawkins proposes directing the spirit of science toward the esthetic value of our communication with nature.

54. Holt, J. *How children learn.* New York: Pitman, 1967.

In this book John Holt reverses his perspective from that of his earlier book, *How Children Fail,* to a more positive survey of the developmental factors which can be used to encourage and extend the natural learning which results from the curiosity present in all young children.

55. Klausmeier, H. J., Davis, J. K., Ramsay, J. G., Fredrick, W. C., and Davies, M. H., Concept learning and problem solving – a bibliography, 1950-64. Wisconsin Research and Development Center for Cognitive Learning, University of Wisconsin, Madison, Wis., 1965. CRP-2850-TR-1. ED 010 201.

This technical report presents a definition of concept, a taxonomy of variables significant in concept learning and problem solving, and a bibliography of articles dealing with both topics.

56. Massialas, B. G., and Zevin, J. *Creative encounters in the classroom.* New York: John Wiley, 1967.

A more challenging type of secondary education should be promoted through teaching the students the basic skills of understanding, critical thinking, and problem solving.

57. Mayer, W. V. Biology – synthesizer of science or disintegrating discipline? *American Biology Teacher,* December, 1968, 30 (10), 799-805.

Through emphasizing the fundamental philosophy and methodology on which all scientific disciplines depend, biology instruction can, and should, become the synthesizer of science.

58. Newton, D. E. The dishonesty of inquiry teaching. *School Science and Mathematics,* December, 1968, 68 (9), 807-810.

This article contends that a purely inductive science classroom is dishonest for four reasons: *(a)* it is not consonant with the demonstrated needs of adolescents; *(b)* it is not an honest preparation for college-bound students; *(c)* it does not honestly reflect the nature of science; and *(d)* it has not been analyzed adequately, so that it is commonly an ineffective and inefficient technique of teaching.

59. Novak, A. Scientific inquiry. *BioScience,* October, 1964, 14 (10), 25-28.

The problem of science education is to avoid teaching science as "acquiry" and to begin teaching it as "inquiry." Scientific inquiry is defined as the total configuration of behaviors involved in the struggle of human beings for reasonable explanations of general phenomena about which they are curious.

60. *The psychological bases of science – A process approach.* Washington, D. C.: American Association for the Advancement of Science, 1965. AAAS Miscellaneous Publication 65-8.

A collection of three working papers describing the objectives of *Science – A Process Approach.* The general objective is to develop transferable intellectual processes for application to continued learning in science. Detailed descriptions of the process goals for each elementary grade level are given under each of the five major objectives: *(a)* observing and classifying, *(b)* communicating, *(c)* measuring, *(d)* recognizing and using spatial relations, *(e)* drawing inferences. For the junior high level, objectives are listed as follows: *(a)* formulating hypotheses, *(b)* making operational definitions, *(c)* controlling and manipulating variables, *(d)* experimenting, *(e)* formulating models, and *(f)* interpreting data.

61. Roughead, W. G., and Scandura, J. M. What is learned in mathematical discovery? *Journal of Educational Psychology,* August, 1968, 59 (4), 283-289.

The major hypothesis (that discovery subjects may discover derivation rules for deriving classes of solutions, but only when the solutions were not initially known) was confirmed.

62. Schwab, J. J. What do scientists do? *Behavioral Science,* January, 1960, 5 (1), 1-27.

Consists of a formulation of principles of enquiry common to scientists, notions which initiate and guide the course of a line of research, and a strategy of enquiry is proposed. Also, it is suggested that this theoretical framework can be used to investigate why scientists have these patterns of enquiry.

63. Shulman, L. S. Psychological controversies in the teaching of science and mathematics. *The Science Teacher,* September, 1968, 35 (6), 34-38.

This article compares the instructional theories of Bruner and Gagne with respect to instructional objectives, instructional styles, readiness for learning, and transfer of learning.

64. Young, D. D. Enquiry – a critique. *Science Education,* March, 1968, 52 (2), 138-142.

After reviewing the various definitions of enquiry, the author points out four needs for enquiry: *(a)* the need for more scientists, *(b)* the need for informed political leadership, *(c)* the need for an informed public, and *(d)* the need for a broader consideration of the sciences. Enquiry is presently limited by conflicting definitions and inadequately prepared teachers.

SECTION III

INQUIRY AS A TEACHING STRATEGY

65. Allender, J. S., Zussman, H., Dutter, D. R., and Jurowski, E. S. The teaching of inquiry skills to fifth grade children. Paper presented at the American Educational Research Association meeting, Chicago, Ill., February, 1968.

Two experimental groups attended a learning center designed to teach inquiry skills under two degrees of structure: for the first group the program was teacher-directed and for the second group the program was self-directed. It was hypothesized that mean increases in problems looked into, questions asked, information requested, and inquiry time would be: *(a)* least for the control group, *(b)* of middle value for the group that attended the learning center whose program was structured by a teacher, and *(c)* greatest for the group that attended a learning center whose program was structured by the student. All of the mean scores for the four measures, with one exception, were in the predicted direction.

66. Andersen, H. O. An analysis of a method for improving problem solving skills possessed by college students preparing to pursue science teaching as a profession. (Doctoral dissertation, Indiana University), Ann Arbor, Mich.: University Microfilms, 1966. No. 67-3997. DA 27:3332-A.

The students enrolled in the investigator-designed problem solving course showed an improved attitude toward problem solving but no significant improvement in skill.

67. Andersen, H. O. Problem solving and science teaching. *School Science and Mathematics,* March, 1967, 67 (3), 243-251.

This article outlines *(a)* the factors which tend to influence the problem solving process, *(b)* the problem solving process itself, and *(c)* some methods which have been used to improve problem solving skills.

68. Anderson, R. D. Using the laboratory to teach the nature of science. *American Biology Teacher,* October, 1968, 30 (8), 633-636.

Using an exercise in the BSCS yellow version, the author describes techniques in teaching in the laboratory.

69. Baughman, M. D. Teaching early adolescents to think. Junior High School Association of Illinois, Urbana, Ill., 1964. ED 011 867.

A series of papers dealing with the teaching of thinking to adolescents is contained in this report.

70. Binter, A. R., and Dewar, J. A. Teacher commitments in a discovery process. *Science Education,* February, 1968, 52 (1), 103-104.

In order to make discovery learning operational in the classroom, the teacher must be committed to the way children go about discovering, to communicating his respect for their learning, and to recognizing the limitations of the discovery process as a teaching tool.

71. Boleratz, J. M. Learning by discovery: An experimental study to measure its effectiveness for teaching value concepts. *Journal of Experimental Education,* Winter, 1967, 36 (2), 13-21.

Irrespective of intelligence, socioeconomic status, and teacher characteristics, students in the experimental group outperformed the control group on the Value Concepts Test designed for this study.

72. Brakken, E. Inquiry involves individualizing, *Instructor,* October, 1968, 78 (2), 95+.

Children who are interested in something want to find out more about that specific something on their own terms and at the particular moment the sense of inquiry strikes them. This desire implies the need for individualized instruction.

73. Butts, D. P. The relationship of problem solving ability and science knowledge. *Science Education,* March, 1965, 49 (2), 138-146.

The hypothesis that there is no correlation between knowledge of the facts and principles of science and problem solving behavior, when that behavior is evaluated according to the degree to which it displays specific patterns, was not rejected. Further, the findings suggest that problem solving behavior is not necessarily characterized by patterned thought.

74. Butts, D. P., and Jones, H. L. Inquiry training and problem solving in elementary school children. *Journal of Research in Science Teaching,* 1966, 4 (1). ED 010 995.

This study showed a significant relationship between inquiry training and changes in the problem solving behaviors of students, but no significant relationship between inquiry training and concept transfer or changes in recall of factual knowledge.

75. Craig, R. C. Recent research on discovery. *Educational Leadership,* February, 1969, 26 (5), 501+.

An excellent review of research on discovery, inquiry, and problem solving strategies as techniques for teaching.

76. De Tornyay, R. M. The effect of an experimental teaching strategy on the problem solving abilities of sophomore nursing students. (Doctoral dissertation, Stanford University) Ann Arbor, Mich.: University Microfilms, 1967. No. 67-17, 548. DA 28:3499-A.

A guided discovery method was not significantly more effective than conventional methods in improving the problem solving abilities of nursing students.

77. Dickinson, M. B. Independent and group learning. Washington, D. C.: National Education Association, (no date). ED 017 332.

A discussion of the value of independent and group learning for the development of thinking processes, such as the ability to reason abstractly and to synthesize.

78. Dubois, E. A. C. Induction and deduction. (Doctoral dissertation, Harvard University) Ann Arbor, Mich.: University Microfilms, 1966. No. 67-5563. DA 28:492-A.

From a fifty-year span of the literature, twelve experiments are reported and criticized. Only six of the twelve experiments permit significant conclusions regarding induction and deduction as treatments, and learning, retention, or transfer as criteria. Of the twelve statistically significant measurements resulting from these six experiments, eleven favor deduction over induction.

79, Edwards, J. C., and Keisler, E. R. The effect of instruction and concomitant variables on multiple categorization ability. Paper presented at the American Educational Research Association meeting, Chicago, Ill., February, 1968.

Since subjects in both instructional treatment conditions made significantly more categorizations than the controls, the findings indicate that children's categorizing skills can be shaped and modified on a group instructional basis. Second, particular instructional techniques may be more appropriate than others for teaching certain classes of concepts; the inferential method taught the subjects to categorize using relational concepts better than the overt presentation of method.

80. Fleckman, B. Improvement of learning division through the use of the discovery method. (Doctoral dissertation, University of Georgia) Ann Arbor, Mich.: University Microfilms, 1966. No. 67-3545. DA 27:3366-A.

The guided-discovery proved more effective than conventional instruction in teaching the concepts and did not appreciably hinder computational learnings.

81. Gagne, R. M., and Brown, L. T. Some factors in the programming of conceptual learning. *Journal of Experimental Psychology*, October, 1961, 62 (4), 313 –.

This study concluded that the discovery method leads to greater transfer than does a rule and example method, a conclusion which is quite consistent with previous findings.

82. Garry, R., Dietmeier, H., Sheehan, A. C., and Decker, M. An investigation of concept development in elementary school science teaching by television. Boston University, Boston, Mass., December, 1963. ED 003 584.

Two types of television programs were produced: information-giving and problem solving. Neither approach was significantly more effective than conventional instruction; however, the problem solving format did result in a higher degree of interaction between the television instructor and the student.

83. Gibbs, R. K. An analysis of the effectiveness of the Biological Sciences Curriculum Study single topic films in teaching hypothesis construction to high school biology students. (Doctoral dissertation, Indiana University) Ann Arbor, Mich.: University Microfilms, 1967. No. 67-16, 399. DA 28:3051-A.

The ability of high school biology students to construct relevant hypotheses was significantly improved through the prescribed teacher instruction which accompanied the use of five different BSCS single topic film loops and was also significantly correlated with the IQ and background of the students.

84. Greenwood, G. E. A study of a system of classroom instruction: Group independent problem solving. (Doctoral dissertation, Indiana University) Ann Arbor, Mich.: University Microfilms, 1967. No. 67-16, 402. DA 28:2117-A.

After being exposed to GRIPS for ten weeks, students change their perception of the teacher's role toward one of viewing the teacher as a problem solver. Their attitudes toward the method of instruction and the future utility of the course reading materials do not significantly change but are favorable. These attitudes are affected by instructor differences in grading

and teaching experience. A definite conclusion could not be reached on subject matter gains. GRIPS does not significantly affect student attitudes toward the six combinations of teaching objectives and teaching methods.

85. Griffin, G. B. A comparison of three supplementary approaches to teaching high school biology in two Georgia high schools. (Doctoral dissertation, University of Georgia) Ann Arbor, Mich.: University Microfilms, 1967. No. 67-16, 222. DA 28:2093-A.

The major research hypotheses were that attainment of scientific knowledge of students taught *(a)* by specified inquiry processes will exceed such attainment of students taught by a specified non-inquiry process, and *(b)* by the Schwab inquiry process will exceed such attainment of students taught by the Suchman inquiry process. Both research hypotheses were rejected at the .05 level of significance.

86. Grobman, A. G. BSCS biology – implementation in the schools. Biological Sciences Curriculum Study, Boulder, Colo. *BSCS Bulletin No. 3*. June, 1964. ED 011 506.

The rationale and content of the BSCS versions are explained; physical facilities, laboratory equipment, and laboratory materials that facilitate teaching BSCS biology are analyzed, and administrative procedures and arrangements for implementing BSCS biology are presented.

87. Hampton, H. F. A comparative study of selected factors of mathematics achievement in homogeneous groups of fifth grade pupils using discovery. (Doctoral dissertation, Oklahoma State University) Ann Arbor, Mich.: University Microfilms, 1967. No. 68-8412. DA 28:4934-A.

The results of this study indicated that: *(a)* there was no significant difference between the performance of the high and low ability groups relative to successes by student or by session, *(b)* the two groups were significantly different relative to the post-test, and *(c)* there was significant correlation between performance in discovery episodes, past achievement in traditional arithmetic, and achievement test scores. An analysis of the results indicated that while the low ability group competed favorably with the high ability group during the discovery episodes, they did not learn as much.

88. Hanson, L. E. Inductive discovery learning, reception learning, and formal verbalization of mathematical concepts. (Doctoral dissertation, Florida State University) Ann Arbor, Mich.: University Microfilms, 1967. No. 67-14, 451. DA 28:1731-A.

The differences between the discovery group and the reception group on measures of achievement, transfer, and retention were not significant for eighth grade subjects but were significant in favor of the discovery group for the college subjects.

89. Hurd, P. D. A study of small group dynamics and productivity in the BSCS laboratory block program. *Journal of Research in Science Teaching*, 1966, 4 (2). ED 010 994.

The performance of incompatible groups in college-bound classes tended to be higher than those in compatible groups. Performance in non-college bound students tended to increase with predicted compatibility.

90. Karlins, M. and Schroder, H. M. Discovery learning, creativity, and the inductive teaching program. *Psychological Reports*, June, 1967, 20 (3, Pt. 1), 867-876. PA 41:14234.

The Inductive Teaching Program contains a set of facts about a specific problem which the student must elicit through the inquiry method. The applications of the ITP in education and educational research are examined, and its linking role between discovery learning and creativity investigations are reviewed.

91. Kersh, B. Y. Directed discovery vs. programmed instruction – a test of a theoretical position involving educational technology. Oregon State System of Higher Education, Monmouth, Ore., March 31, 1964. ED 003 616.

This project emphasizes the design of instructional units rather than the research problem.

92. Lee, A. E. The development of new supplementary teaching materials and an analysis of their potential use in the high school biology curriculum, final report. CRP-S-451: University of Texas, Austin, Texas, August, 1966. ED 015 138.

Materials called "Springboards for Discussion" were demonstrated to be effective teaching devices to emphasize processes and procedures of scientific inquiry.

93. Lee, M. A. Development of inquiry skills in ungraded social studies classes in a junior high school. (Doctoral dissertation, Indiana University) Ann Arbor, Mich.: University Microfilms, 1967, No. 68-2316. DA 28:3367-A.

A method of instruction can be designed so that pupils can be explicitly taught to develop and utilize skills in problem solving without loss of pupil achievement in factual information. Pupils who never have been engaged in classes designed to develop problem solving skills fail to show improvement in acquiring or refining these skills.

94. Luck, W. E. An experimental comparison of direct-and-detailed method and directed-discovery method of teaching selected automotive topics to senior high school industrial arts students. (Doctoral dissertation, Oklahoma State University) Ann Arbor, Mich.: University Microfilms, 1966. No. 67-7252. DA 27:4156-A.

Although it was reported in the findings that there are no significant differences between the two methods, the computed results of this study definitely indicate that the subject groups included in the higher and lower levels of intelligence, which were instructed by the directed-discovery method, scored higher on both tests than did the direct-and-detailed group.

95. Mascolo, R. P. New conceptual schemes and inquiry training: Some effects upon new learning. (Doctoral dissertation, New York University) Ann Arbor, Mich.: University Microfilms, 1967. No. 67-11, 114. DA 28:1345-A.

The hypothesis predicting greater affective meaning for groups receiving knowledge organized around the key conceptual schemes of the discipline was supported. Organization of subject matter around the key conceptual schemes seemed to increase performance in conceptualizing new material, whereas formal inquiry training had no significant effect.

96. Mason, J. M. The direct teaching of critical thinking in grades four through six. *Journal of Research in Science Teaching*, 1963, 1 (4). ED 011 239.

Science units constructed to directly teach critical thinking proved more effective than conventional science units in the teaching of critical thinking.

97. Montague, E. J., and Ward, R. M. The development of problem solving abilities in secondary school chemistry. *Journal of Research in Science Teaching,* 1968, 5 (4), 354-356.

The unexpected results of this study suggest that students with investigative experience in the chemistry laboratory do not learn to transfer abilities in critical thinking any better than those with traditional experiences or that teachers may not use these approaches with equal effectiveness.

98. Murphy, G. W. Content versus process centered biology laboratories, part II: The development of knowledge, scientific attitudes, problem solving ability, and interest in biology. *Science Education,* March, 1968, 52 (2), 148-162.

No significant difference was discovered between the content- and process-centered laboratories with respect to the development of knowledge, scientific attitudes, problem solving ability, or interest in biology.

99. Neal, L. A. Techniques for developing methods of scientific inquiry in children in grades one through six. *Science Education,* October, 1961, 45 (4), 313-320.

This paper describes a wide variety of techniques for developing the ability of pupils to use methods of scientific inquiry.

100. Novak, A. Scientific inquiry in the laboratory. *American Biology Teacher,* March, 1963, 25 (3), 342-346.

This article describes some laboratory experiences designed to give the student some understanding of the problems and operations of a scientist.

101. Parakh, J. S. A study of teacher-pupil interaction in BSCS Yellow Version biology classes. *American Biology Teacher,* December, 1968, 30 (10), 841-848.

This article focuses on describing and analyzing the nature of the teacher-pupil interaction in selected BSCS Yellow Version biology lecture-discussion classes, and compares interaction scores of each selected teacher while teaching two different groups of pupils.

102. Pipe, P. *Practical programming.* New York: Holt, 1966.

Pipe appeals to teachers to state objectives behaviorally. He says it is amazing how many teachers and instructors say, "Yes, I can see how useful it is to have these careful statements of objectives for most courses. But in my course it is different. . .."

Objectives can be improved by asking three questions: *(a)* what will the student be *doing* when he is demonstrating proficiency? *(b)* under what conditions will this behavior occur? *(c)* what is the level of acceptable performance? (Begin with an action word.) Most people, when they first try to write behavioral objectives, seem unable to think small enough.

103. Raun, C. E., and Butts, D. P. The relationship between the strategies of inquiry in science and student cognitive and affective behavioral change. *Journal of Research in Science Teaching,* 1968, 5 (3), 261-268.

Criterion variables of behavior were tested to determine their relationship to the strategies of inquiry in science. It appears that none of the strategies of inquiry in science by themselves can be used to predict behavioral change in all of the behavioral criteria.

104. Renner, J. W., and Ragan, W. B. *Teaching science in the elementary school.* New York: Harper & Row, 1968.

Includes chapters differentiating inquiry and discovery from other teaching orientations, teacher responsibilities in discovery orientations, techniques to involve children with science and discovery, and an especially significant treatment of the importance of "freedom of mind" to the application of rational powers in problem solving and decision making.

105. Richard, P. W. Experimental individualized BSCS biology. *The Science Teacher,* February, 1969, 36 (2), 53-54.

An experiment was undertaken at the Laboratory School, Colorado State College, to determine the extent to which self-directed learning could be strengthened through individualization of biology and the extent to which laboratory biology could be individualized.

106. Richardson, C. E., and Oliver, L. E. Intermediate science curriculum study project as viewed by participating teachers. *School Science and Mathematics,* December, 1968, 68 (9), 785-790.

Open-ended experimentation is more appropriate to the nature of the early adolescent than is highly directed instruction.

107. Richardson, E. Inquiry in instructional television: A pilot project. *Audiovisual Instruction,* November, 1967, 12 (9), 915-916.

This interim report describes the progress of a California-based project to develop instructional television programs in the inquiry mode. Under the direction of KQED, pilot tapes were prepared to illustrate inquiry modes.

108. Rubadeau, D. O. A comparison of learner-centered and teacher-centered learning. (Doctoral dissertation, University of Rochester) Ann Arbor, Mich.: University Microfilms, 1967. No. 67-13, 665. DA 28:1710-A.

The learner-centered group learned more efficiently and equally as effectively as the teacher-centered group.

109. Salstrom, D. A comparison of conceptualization in two types of guided discovery science lessons. (Doctoral dissertation, Kent State University) Ann Arbor, Mich.: University Microfilms, 1966. No. 67-9428. DA 28:407-A.

This study gives evidence that conceptualization may be aided through the tentative proposal to sixth grade pupils of a workable conceptual framework. This seems to be true even for pupils working individually during inquiry, without the stimulation, information, and cueing afforded by the oral participation of their classmates.

110. Sanders, N. *Classroom questions: What kinds?* New York: Harper & Row, 1967.

111. Schuck, R. F. The comparative effects of the BSCS curricula upon students exposed to instructional strategies incorporating set induction procedures. *School Science and Mathematics,* October, 1968, 68 (7), 601-608.

Significant differences, favoring the experimental group, were found between the experimental and control groups in both pupil achievement and pupil perception of effective teaching; however, these results were not significantly effected by the BSCS version used.

112. Schwab, J. J. The teaching of science as enquiry. The Inglis Lecture in *The teaching of science*. Cambridge, Mass.: Harvard University Press, 1962.

The case for science teaching to reflect the recent change from stable to fluid enquiry in science, and suggestions for effecting this change in the classroom are presented.

113. Science Education Information Analysis Center. *Science education information report: Bibliography 1, instructional procedures.* Ohio State University, Columbus, Ohio, December, 1967. ED 015 077.

Reported are over 180 citations to selected documents related to instructional procedures in science education.

114. Scott, N. C., and Sigel, I. E. The effects of inquiry training in physical science on creativity and cognitive styles of elementary school children. Merrill Palmer Institute, Detroit, Mich., 1965. ED 003 700.

Only in the cognitive style tasks did the inquiry approach show significant effects on conceptual activities. The inquiry process appeared generally to encourage and develop an exploratory attitude on the part of the individual learner which led him beyond basic overt perception.

115. Shallcross, D. J. A creative problem solving course. *NEA Journal,* February, 1967, 56 (6), 57.

This article describes a creative problem solving course offered at the 11th and 12th grade levels. The techniques most commonly used in the course are brainstorming or using checklists, such as Alex F. Osborn's *Idea-Spurring Questions.*

116. Shockley, W., and McDonald, F. J. Teaching scientific thinking at the high school level. School of Education, Stanford University, Stanford, Calif., October, 1964. ED 003 456.

The study had two objectives: *(a)* to teach the process of search for an answer, and *(b)* to teach the logical structure of important principles.

117. Skinner, R. Inquiry session: An assist for teaching science via instructional television in the elementary schools. *Journal of Research in Science Teaching,* 1968, 5 (4), 346-349.

One of two types of follow-up was used after each televised lesson, either "typical discussion" or "inquiry session." There did not seem to be a consistent pattern in pupil achievement when groups were compared according to the type of teacher follow-up.

118. Sloan, F. A., and Pate, R. T. Teacher-pupil interaction differences between School Mathematics Study Group and traditional mathematics. CRP-S-137. University of Oklahoma, Norman, Okla., 1964. ED 003 462.

Significantly more new mathematics teachers than traditional mathematics teachers *(a)* used analysis questions which elicited spontaneous responses from the students, and *(b)* paid particular attention to content development.

119. Suchman, J. R. Rebuilding the science program: Inquiry training in the elementary school. *The Science Teacher,* November, 1960, 27 (8), 42-49.

Fifth-grade students successfully developed transferable inquiry strategies, made fewer untested assumptions, and made and tested more hypotheses as a result of their participation in an inquiry training program.

120. Suchman, J. R. The elementary school training program in scientific inquiry. University of Illinois, Urbana, Ill., June, 1962. ED 003 530.

Marked effects on the motivation, autonomy, and questioning fluency of the experimental group of children were observed as a result of their participation in the training program.

121. Suchman, J. R. The motication to inquire.*The Instructor,* October, 1965, 75 (2), 26+.

This article is an excellent statement on the relationship between closure and the static mind as opposed to that between opensure and curiosity. The motivation to inquire seems to follow a personal reluctance to accept things as settled and a persistence in holding explanations tentative.

122. Taber, J. I., Glaser, R, and Schaefer, H. H. *A guide to the preparation of programmed instructional material.* Department of psychology, University of Pittsburgh, Pittsburgh, Pa., 1962.

123. Ter Keurst, A. J., and Martin, J. M. Rote vs. discovery learning. *School and Community,* November, 1968, 55 (3), 42+.

The hypothesis, that school children in the middle elementary grades achieve better results in learning and retaining a simple arithmetical procedure when the instruction emphasizes rote learning rather than learning by discovery, was confirmed.

124. Twelker, P. A. Two types of teacher-learner interaction in learning by discovery: Final report. Oregon State System of Higher Education, Monmouth, Ore., September, 1967. ED 018 117.

No significant difference was found between the effectiveness of reinforcement by praise only, reinforcement by praise plus indirect guidance on how to process information available to the learner, and direct presentation of the same information intended for discovery.

125. VanDeventer, W. C. An inquiry approach to interdisciplinary seventh grade science. *Journal of Research in Science Teaching,* 1968, 5 (4), 373-384.

Junior high school furnishes a final opportunity to take a meaningful look at interdisciplinary science. This interdisciplinary science, however, needs to be planned in terms of problems, ideas, and understandings, rather than a limited factual survey of conventional science fields.

126. Wills, H. Transfer of problem solving ability gained through learning by discovery. (Doctoral dissertation, University of Illinois) Ann Arbor, Mich.: University Microfilms, 1967, No. 67-11, 937. DA 28:1319-A.

This study has shown that students can significantly improve their problem solving ability as a bonus to content learned by discovery.

127. Worthen, B. R. Discovery and expository task presentation in elementary mathematics. *Journal of Educational Psychology,* February, 1968, 59 (1, Pt. 2).

Discovery teaching proved superior to expository methods with respect to retention and transfer but inferior with respect to initial learning.

128. Worthen, B. R. A study of discovery and expository presentation: Implications for teaching. *Journal of Teacher Education,* Summer, 1968, 19 (2), 223-242.

Although the expository method yielded greater initial learning, the discovery method proved superior in retention, transfer, and development of problem solving skill.

129. Yager, E. Y. Comparison of teaching outcomes between two teachers of secondary biology. *American Biology Teacher,* December, 1968, 30 (10), 816-819.

Students of the indirect teacher showed more growth on a test measuring mastery of facts. However, on another achievement test which requires some skill in interpreting data as well as some ability to apply information, the students of the two teachers studied were nearly equal. The students with the indirect teaching methods seemed to understand the nature of science better than did students taught by direct means.

SECTION IV

PREPARING THE TEACHER FOR INQUIRY

130. Biological Sciences Curriculum Study. *Laboratory blocks in teaching biology*. BSCS Special Publication No. 5. Biological Sciences Curriculum Study, University of Colorado, Boulder, Colo., 1967.

Describes the objectives and use of the laboratory block materials.

131. Biological Sciences Curriculum Study. *New materials and techniques in the preparation of high school biology teachers*. BSCS Special Publication No. 6. Biological Sciences Curriculum Study. University of Colorado, Boulder, Colo., 1969.

Includes sections on testing and evaluation and on pre- and in-service training of biology teachers.

132. *BSCS Newsletter 32*. The teacher. Biological Sciences Curriculum Study. University of Colorado, Boulder, Colo., September, 1967.

A collection of articles on the BSCS teacher preparation activities.

133. Curtis, W. C. Teacher-training for process orientated science instruction. *Science Education*, December, 1967, 51 (5), 494-498.

This study outlines the understandings a teacher should have of the processes of systematic scientific investigations. Specific competencies are described under the following major headings: *(a)* data collection, *(b)* data processing, *(c)* data interpretation, *(d)* communication.

134. Lee, A. E. The experimental approach in teaching biology: An introduction to the BSCS Laboratory Block Program. *American Biology Teacher*, November, 1961, 23 (9), 409-411.

The purpose of this article is to acquaint the teacher with the objectives and rationale of the BSCS Laboratory Block Program. Some presentations by other laboratory block authors give the reader an idea of how the objectives can be reached.

135. McCormick, F. R. The outdoor laboratory: In-service education in the processes of science. (Doctoral dissertation, University of Arkansas) Ann Arbor, Mich.: University Microfilms, 1967. No. 67-12, 883. DA 28:1330-A.

The teacher's understanding of the processes of science increased to a small degree as a result of participation in the experimental program. The findings also appear to justify the conclusion that the experimental program provided at least as much, and possibly more, knowledge of biological principles than did the control and that participation in the program effected changes in teaching practices.

136. Raack, M. L. The effect of an in-service education program on teacher verbal behavior. (Doctoral dissertation, University of California, Los Angeles) Ann Arbor, Mich.: University Microfilms, 1967. No. 67-12, 231. DA 28:1332-A.

As a result of an experimental program to develop inquiry teaching strategies, teachers showed gains in their acceptance of pupil responses and in use of praise and encouragement. These gains were accompanied by predicted increases in the percentage of total pupil participation as well as pupil initiation of interaction. While teaching behavior became more indirect, total teacher talk went down, as predicted, for the majority of teachers. Also as predicted, teachers affirmed a description of the teacher's classroom role congruent with an indirect approach to teaching by the end of the program.

137. Schwab, J. J. (Supervisor) BSCS *Biology teachers' handbook.* New York: John Wiley, 1963. 2nd Edition, 1970. Klinckmann, E. (Supervisor).

The character of the BSCS approach to biology, some materials for teaching biology as enquiry, materials from statistics and from the physical sciences relevant to biology, and resource materials are included.

138. Smith, R. B. The implications of inquiry structures for the teacher education curriculum. *Journal of Teacher Education,* Fall, 1968, 19 (3), 338-343.

Through an analysis of the conception of knowledge implicit in the new curricula, the author constructs an instructional model for use in the teacher education curriculum.

SECTION V

EVALUATING THE INQUIRY PROCESS

139. *BSCS Newsletter 19.* Evaluation supplement. Biological Sciences Curriculum Study, University of Colorado, Boulder, Colo., September, 1963.

A report of the 1961-62 BSCS evaluation program.

140. *BSCS Newsletter 30.* Evaluation issue. Biological Sciences Curriculum Study. University of Colorado, Boulder, Colo., January, 1967.

Contains articles on evaluation issues, a report of the 1964-65 evaluation program, and a bibliography and abstracts on research involving BSCS materials.

141. Butts, D. P. An inventory of science methods. University of Texas. Science Education Center, Austin, Texas, August, 1966. ED 010 338.

The TAB Science Test was designed to sample inquiry behaviors by presenting the student with *(a)* a specific problem, *(b)* a list of clues to help him solve the problem, and *(c)* the opportunity to gather clue data when they are needed.

142. Butts, D. P., and Jones, H. L. The development of the *TAB Science Test. Science Education,* December, 1967, 51 (5), 463-473.

The reliability and validity of a tab-item test to measure the behaviors of inquiry were assessed.

143. Covington, M. V. A childhood attitude inventory for problem solving. University of California, Berkeley, Calif., ca. 1966. ED 015 497.

This paper describes a 60-item, group-administered, paper-pencil attitude inventory comprised of two scales, one assessing the child's belief about the nature of the problem-solving process (scale I) and the other assessing the child's self-confidence in undertaking problem-solving activities (scale II).

144. Cox, R. C. Item selection techniques and evaluation of instructional objectives. *Journal of Educational Measurement,* 1965, 2. ED 014 805 (abstract only).

This study is designed to evaluate the effect of statistical item selection on the structure of the final evaluation instrument as compared with the structure of its original item pool.

145. Hammond, R. L. Evlauation at the local level. Project EPIC, Tucson, Ariz., 1967. ED 016 547.

This article reports a new systematic approach to the problem of evaluation of innovations.

146. Jeffrey, J. C. Identification of objectives of the chemistry laboratory and development of means for measuring student achievement of some of these objectives. (Doctoral dissertation, University of Texas) Ann Arbor, Mich.: University Microfilms, 1965. No. 66-1928. DA 28:1732-A.

This study classifies the student performance objectives of the chemistry laboratory into six major categories and proposes type-tests for measuring achievement in three of these categories. Categories listed are: *(a)* communicative competence, *(b)* observational competence, *(c)* investigative competence, *(d)* reporting competence, *(e)* manipulative competence, and *(f)* laboratory discipline.

147. Kaplan, E. H. The Burmester *Test of aspects of scientific thinking* as a means of teaching the mechanics of the scientific method. *Science Education*, October, 1967, 51 (4), 353-357.

It appears that the Burmester *Test of aspects of scientific thinking* is useful as an aid in acquainting freshman college students with the mechanical aspects of the scientific method. A proposed technique for utilizing the test for pedagogical purposes, involving the use of one or two practice sessions with an alternate form, resulted in a highly significant increment of improvement.

148. Keisler, E. R. Teaching children to discover – a problem of goal definition. Southwest Regional Educational Laboratory, Inglewood, Calif., 1968. ED 018 833 (abstract only).

The purpose of this report is *(a)* to clarify certain aspects of teaching children to discover, and *(b)* to offer directions for the development of problem solving tests.

149. Klinckmann, E. The BSCS grid for test analysis. *BSCS Newsletter 19*. Biological Sciences Curriculum Study, Boulder, Colo., 1964, 17-21.

The BSCS adaptation of the *Taxonomy*, for examination of tests to determine if the tests actually incorporate BSCS aims, is presented. Two BSCS tests and the Cooperative Biology Test are analyzed. A difficulty encountered was that of classifying test items when the relevant prior learning experiences of the students are unknown.

150. La Shier, W. S., and Westmeyer, P. The use of interaction analysis in BSCS laboratory block classrooms. *Journal of Teacher Education*, Winter, 1967, 18 (4), 439-446.

151. Lee, A. E. (Ed.) Research and curriculum development in science education: 1. The new programs in high school biology. Publication No. 6720. Science Education Center, University of Texas, Austin, Tex., 1968.

A collection of research reports concerned primarily with the evaluation of new biology programs.

152. Lindvall, C. M. *Testing and evaluation: An introduction*. New York: Harcourt, Brace and World, 1961.

This volume accomplishes two tasks: *(a)* stressing the importance of determining and classifying objectives before meaningful evaluation can take place, and *(b)* furnishing concrete practical help in the writing of test items. Nearly one hundred pages are devoted to this latter task, providing excellent examples of test items of various types which can be used by classroom teachers.

Also included are discussions of standardized tests currently available and advice on running a school-wide program of testing and evaluation.

153. Pfeiffer, I, and Davis, O. L., Jr. Teacher-made examinations: What kinds of thinking do they demand? *Bulletin of the National Association of Secondary School Principals*, September, 1965, 49 (302), 1-10. ED 015 170.

The taxonomic classification of test items in the semester examinations of ninth-grade teachers was studied. Percentage of items in each of the six major categories were compared across courses, ability group levels, and programs of study. In all cases the highest percentage of questions fell into the knowledge category. Second highest was application. Very few questions were classified into the upper three categories, and these were found primarily in some English courses. It was suggested that teachers should be aware of which cognitive processes they are emphasizing in their test questions, and that there should be more emphasis on the higher objectives for all students in all courses. Also, a study should be made of teaching emphases: are they the same as those of the examination questions?

154. Schmidt, D. J. Test on understanding science: A comparison among several groups. *Journal of Research in Science Teaching*, 1967, 5 (4), 365-366.

Of secondary science methods students, elementary science survey students, and working scientists, the working scientists score highest on *TOUS*; however, their mean score is ten points less than the maximum possible score, indicating that a respectable score on *TOUS* may be somewhat less than previously suspected.

155. Shaffer, V. F. The categorization of student inquiries and the responses made within the context of classroom interaction. (Doctoral dissertation, University of Illinois) Ann Arbor, Mich.: University Microfilms, 1966. No. 67-6729. DA 27:4158-A.

The purpose of the study was to investigate and describe the inquiries made by gifted junior and senior high school students during classroom discussions, as well as the responses made to the inquiries.

156. Steiner, H. E., Jr. A study of the relationships between teacher practices and student performances on selected inquiry process behaviors in the affective domain in high school biology classes. (Doctoral dissertation, University of Texas at Austin). 1970.

The purpose of this study was to develop instruments (both observational and pencil-paper) to measure selected affective objectives and determine how well student performance correlated with selected teacher practices. This study was based on Bingman, R. M. (Ed.) *Inquiry objectives in the teaching of biology*, Kansas City, Mo.: Mid-continent Regional Educational Laboratory, Position paper, 1 (1), 1969.

157. Stilwell, M. E. The development and analysis of a category system for systematic observation of teacher-pupil interaction during geometry problem solving activity. (Doctoral dissertation, Cornell University) Ann Arbor, Mich.: University Microfilms, 1967. No. 68-893. DA 28:3083-A.

This project is directed to the problem of better understanding the process of problem solving in mathematics education seen in the interaction between teacher and pupils during actual classroom activity.

158. Taba, H., Levine, S., and Elzey, F. F. Thinking in elementary school children. CRP-1574. San Francisco State College, San Francisco, Calif., 1964.

Contains sets of categories that can be used for categorizing teacher-student verbal behaviors to make certain teaching strategies more explicit.

159. Turner, G. C., and Hettick, V. An evaluative study of teacher constructed test items for BSCS biology. California State College, Fullerton, Calif., December, 1967. ED 018 371.

This study provides a portfolio of several thousand field-tested multiple choice test items coordinated with the chapters of the BSCS Yellow Version textbook. The protocol described for developing test items, for field testing these items, and for evaluating them could be adapted by other teaching groups in developing test items appropriate to their own teaching situation.

160. Wilds, P. L., and Zachert, V. Multicategorical evaluation of performance in clinical problem solving tests. Georgia Medical College, Augusta, Ga., January, 1968. ED 017 025.

This project attempted to determine if numerical scoring systems for clinical problem solving tests could be developed which would measure the effectiveness of different instructional methods in teaching clinical problem solving skills.

161. Woodburn, J. H. The methods and the procedures of science: An examination. *Science Education,* December, 1967, 51 (5), 481-482.

This article reports the availability of a 50-item test of students' understanding of the methods and procedures of science.